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SUMMARY REPORT, TASK V

Contract Number JPL 951720

1 August 1968

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This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

ABSTRACT

The work reported herein is a continued investigation of the Dual Mode Hydrazine propulsion system for attitude control and maneuvering of an advanced interplanetary space probe. An experimental electrolysis module was constructed and performance measured over a variety of operating conditions. The module was installed in a tank which allowed gas pulse venting in each of three attitudes as a demonstration of operating capability in +1 and -1 gravity. Test objectives were met and information obtained which will allow the design of an improved model. That design will be executed as Task VI of the current program.

INTRODUCTION AND SUMMARY

This report is a summary of work performed under Task V of JPL Contract 951720 during the period February 1, 1968 to August 1, 1968. The objective of Task V was to build and test a breadboard model hydrazine electrolysis cell module. The design was based on information obtained in the preceeding Task IV, a laboratory investigation of the hydrazine electrolysis process. The principal investigator in Task V was Mr. N. E. Morgan.

The electrolysis cell is a key component in the Dual Mode Hydrazine System, the system devised at Hughes and analyzed in detail under Tasks I-III of this contract. This multipurpose integrated propulsion system is intended primarily to provide attitude control and maneuvering thrust for interplanetary space probes and other three-axis controlled spacecraft. In operation, attitude control gas is generated by electrolysis of hydrazine within the main tankage and supplied to small gas thrusters. Liquid propellant is also supplied from the same tankage to catalytic thrusters which typically are small, as required for most maneuvers, but may include larger engines for midcourse corrections and retro.

The present study is directed primarily toward investigation of the electrolysis cell module but was tested as an assembly with a flight type 6A1-4V titanium tank. Capability of zero gravity gas pulsing operation was included in the design. Liquid expulsion in zero gravity was considered to be essentially within the state-of-the-art of surface tension control screens and was not part of the design as tested.

DESIGN

The electrolysis cell assembly contains a cylindrical fluted graphite anode and aluminum screen cathode which are separated by a glass cloth wick. This electrode assembly is enclosed by an inner and outer aluminum shell. Gas is collected and stored in the hollow interior of the unit where separation from liquid is assisted by fine mesh screens. A complete description of the design and pictures of the hardware is found in the following section.

Several materials of construction were employed in order to determine their suitability in this specific application. The system is unique both because of the electrolysis process and the hydrazine which contained small amounts of oxalic acid electrolyte for the present experiments. Of the several materials, only the 6061-T6 aluminum used for some of the structural parts appeared to be affected in any way, which was moderate staining. The graphite anode, 5056 aluminum cathode, 304L stainless steel gas compartment screens and the 6A1-4V titanium tank were in excellent condition after several weeks of exposure which included over 500 hours electrolysis time.

DESIGN VERIFICATION TESTS

Performance was measured over a range of voltages, electrolyte concentration and liquid volume. Typically, the cell draws current between 1.5 and 3.0 amperes when supplied with hydrazine containing 0.5 to 1.5% electrolyte and operated at voltage of 1.5 to 2.5 volts. Four watts of power at the nominal 2 volt, 2 amp design point will generate .0026 lbs gas/hr. Comparison of actual measurements with the theoretical 1521 ampere-hours per pound of gas showed agreement within the experimental error.

Some variation of cell resistance with liquid fill volume was observed, indicating that the wick is not entirely efficient in earth gravity. This is thought not to be a problem because, in low gravity, capillary action will be strong enough to saturate the wick fully.

ENVIRONMENTAL TESTS

Current was measured as a function of propellant temperature over the range of $+40^{\circ}F$ to $+120^{\circ}F$. The apparent gross temperature coefficient of current (or gas generation rate) was $0.6\%/^{\circ}F$ under typical operating conditions.

GAS VENTING DEMONSTRATION

Drop tower or aircraft ballistic trajectory tests are not long enough in duration to test zero gravity behavior of the electrolysis module and gas venting system. However, it has been possible to design a module which will operate in +1 or -1 earth gravity in all attitudes. This is not considered full proof of zero gravity capability but contributes materially to design confidence.

Demonstration of gas venting was performed with the tank assembly in each of three attitudes: upright, inverted and on one side. In all cases, gas was vented which contained only a trace of liquid. The source of the small amount of liquid observed has not been determined but could be the wet gas storage compartment screens or may have been present in the gas lines before start of the venting. In either event, independence of tank attitude shows the basic liquid-gas separation scheme is successful.

DESIGN MODIFICATION

During the course of the test program, three main problems were encountered, all due to effects of differential pressure. The problems were: liquid in vented gas pulses; increase in cell current following venting; a slow decay of current with operating time.

These problems were essentially eliminated 1) by adding an orifice and plenum external to the tank assembly to prevent rapid internal pressure changes and 2), connection of the gas storage compartments to the tank ullage volume by external plumbing. It will be possible to eliminate these components in the Task VI design.

LIFE TEST

A life test was begun but will not be completed until the end of the program. Operation to date is normal except for a very slow current decay which is attributed to the accumulation of gas bubbles on the anode. This problem may be eliminated by modifying the anode configuration.

DESIGN OF TEST HARDWARE

The primary function of the electrolysis cell assembly is generation of a mixture of hydrogen and nitrogen gas. Use of separated gases is of no advantage, either for thrusting or ullage pressurization and would add greatly to the design complexity. Also, t here is no means of altering the chemistry of the electrolysis process to produce a larger proportion of hydrogen, because the normal reaction converts all of the combined hydrogen to the elemental gas.

A second important function of the electrolysis cell assembly is to separate liquid droplets from the gas and subsequently control location of the ullage bubble. It would be possible to attach the general problem of venting gas in zero gravity from a tank containing both gas and liquid but this appears to be unnecessary for the present system. Instead, it is possible to trap the gas used for thrusting at the site of generation. When liquid is used from the tank replacement gas flows out of the trapped volume until pressure is equalized. Details of the design and pictures of the hardware tested are presented below.

PRELIMINARY DESIGN

Figure 1 shows the basic electrolysis cell assembly as installed in a test tank. The assembly is axisymmetric about the central support rod with the exception of the electrode connections and a single communicating pipe between the electrode area and the top gas storage compartment.

Since this design is very similar to the unit tested, discussion of the operation is deferred to the following section. The main differences are:

1. The gas outlet was changed from the top of the tank to the bottom flange. This allowed elimination of the lip seal shown.

2. The number of internal screen compartments was reduced to four from the seven shown.

3. The overall length was reduced and the flange modified to accommodate a smaller test tank which became available.

DESIGN TESTED

Figure 2 is a slightly simplified sketch of the hardware which was built. The electrode sub-assembly is a completely self-contained module which is preassembled before installation into the tank. The electrode sub-assembly is mounted on a central support rod which in turn mounts on a flange which forms the tank closure. This flange contains ports for liquid filling, draining and feed to gas and liquid thrusters. Also the flange includes ports for electrical power and a thermocouple feed-through. The upper end of the central support rod is supported within a recess in the top of the tank.

SECTION A-A

DESIGN TESTED (continued)

The electrodes are concentric cylinders with the anode on the inside and the cathode on the outside. The electrodes are separated by a layer of glass cloth which acts as a wick and extends beyond the end of the electrodes into areas of known liquid location in the tank. This provides a liquid feed to the electrodes regardless of the tank attitude. The anode is a hollow cylinder of fine grain graphite (ATJ) with longitudinal grooves along the full length of the outside surface to provide for passage of the gas liberated at the surface. The cathode is a 30 mesh aluminum screen (alloy 5056). Previous experiments indicated that 304L corrosion resistant steel is satisfactory but aluminum was used here as part of a continuing effort to investigate other materials. Likewise, the mounting flange and top cap were made from 6061 T6 aluminum. The electrodes are held between two end caps and are electrically insulated from each other and from the surrounding structure. The cathode is insulated but may be grounded to the tank if desired. The mounting of the electrodes was slightly modified from that shown in Figure 2 to make fabrication and assembly easier. The revised electrode mounting configuration is shown in sketch of Figure 3. The seal between the outer shell and the cathode screen, which is coated with polyethylene film in the seal area, is shown to be an O ring. This seal is not critical and has also been accomplished successfully by a Teflon tape wrapping. The electrodes are enclosed in an annular space formed between two shells made of aluminum tubing. The outer shell forms the outside enclosure of the electrode subassembly and is separated from the cathode screen by a small gas passage space. The inner shell is inside the anode and forms the outer enclosures for the zero g gas venting device. The gas compartment screens were prefabricated into cup shaped assemblies which are located and retained by Teflon spacers along the central support/gas vent tube. Figure 4 is a photograph of the actual parts and Figure 5 through 8 shows the module in various stages of assembly.

OPERATION

The cell module will be controlled by a pressure switch in an operational system and will generate gas until a predetermined pressure is reached. Gas is required both for thrusting and ullage makeup in the main tank.

Figure 9 shows the assembly as it would generate gas in normal operation. Liquid enters the electrode area through the wick and is converted to gas at both the anode and cathode surfaces. The generated gas escapes through the cathode screen into the space next to the outer shell and from the anode into the longitudinal flutes. The gas must then pass upward in the diagram and enter the top screen compartment via the gas manifold and connecting pipe. In order to reach operating pressure the gas must fill the screen compartments and at least a small amount of additional gas must enter the main tank to replace the liquid used.

HYDRAZINE ELECTROLYSIS CELL

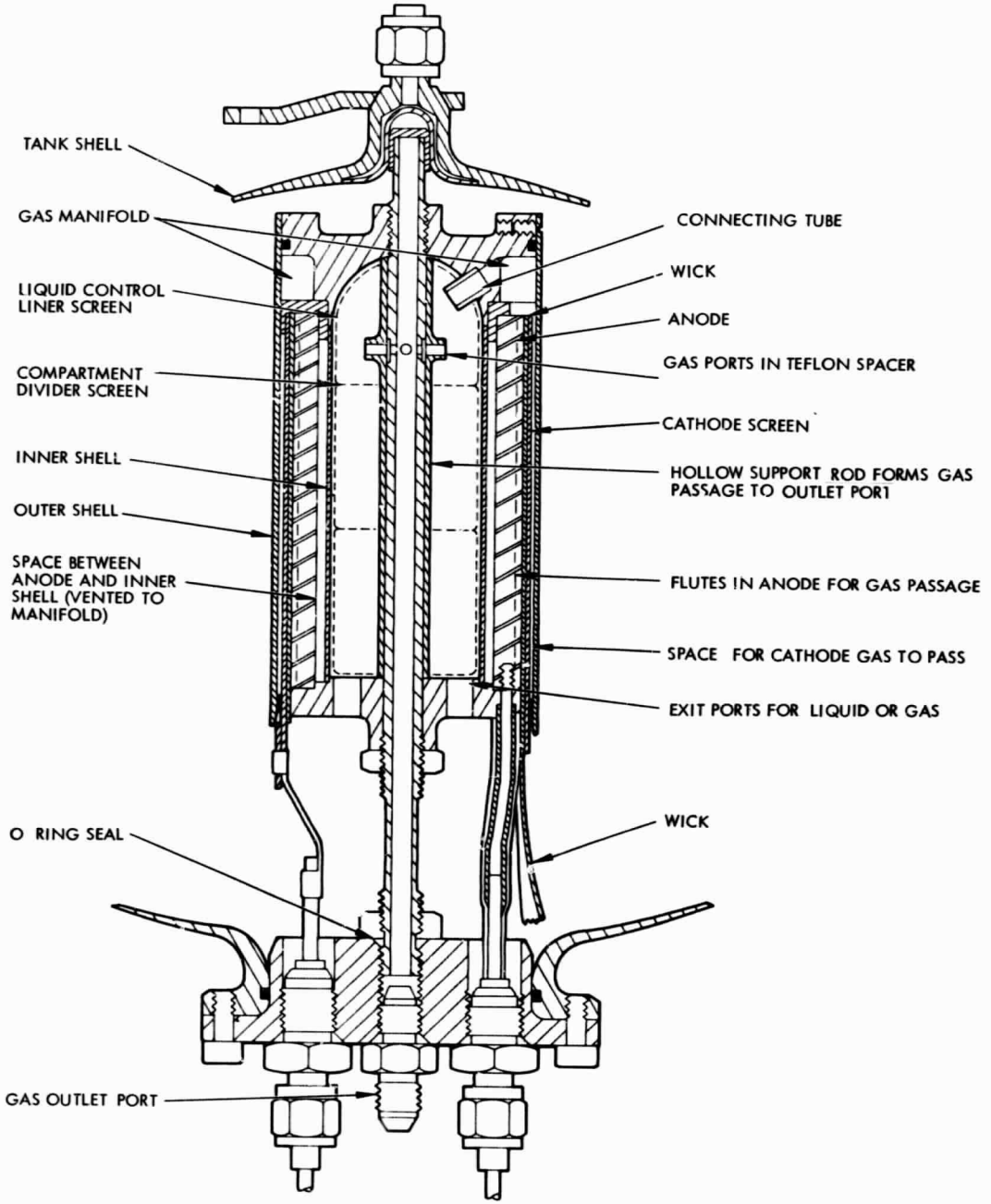

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FIGURE 3

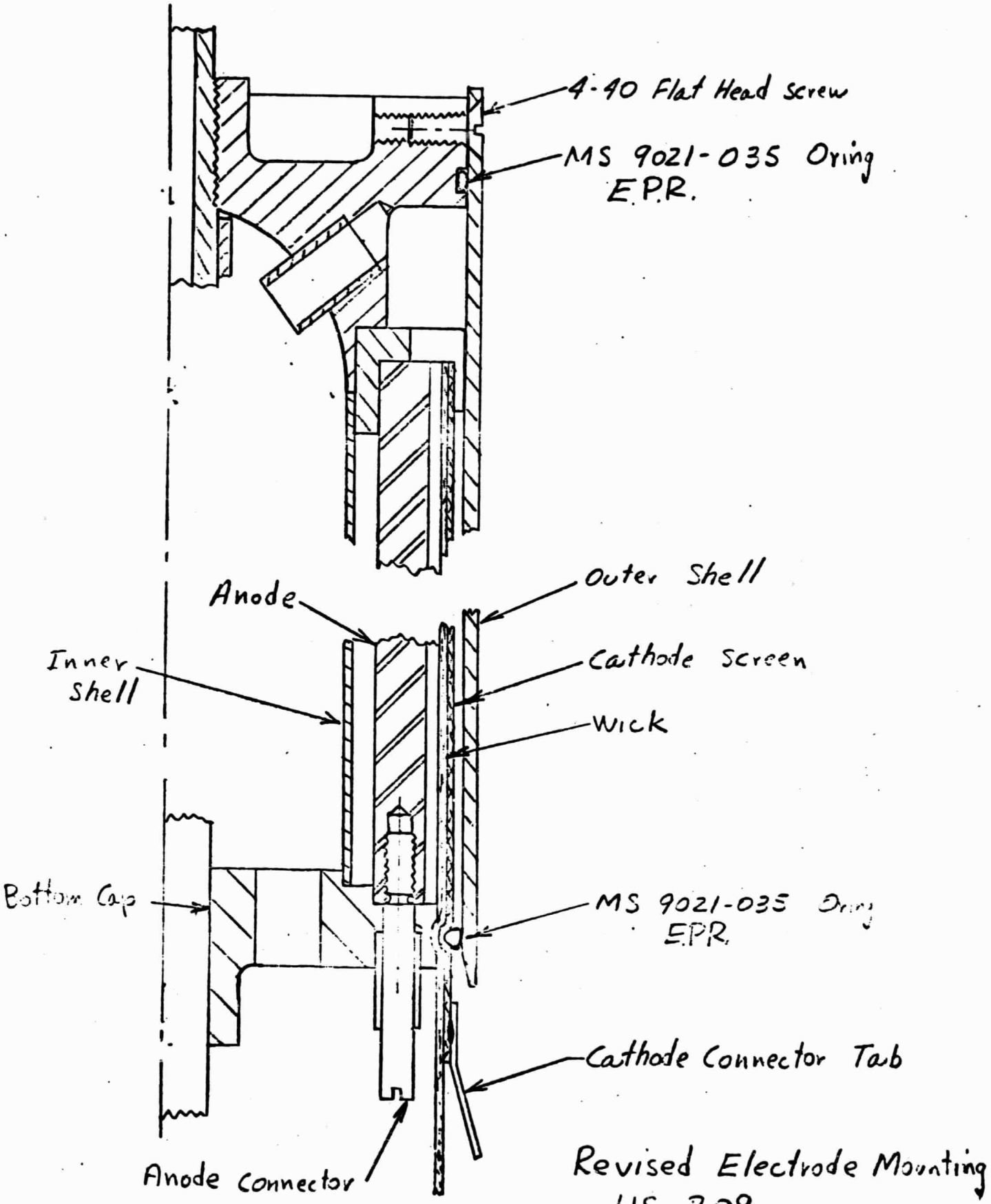
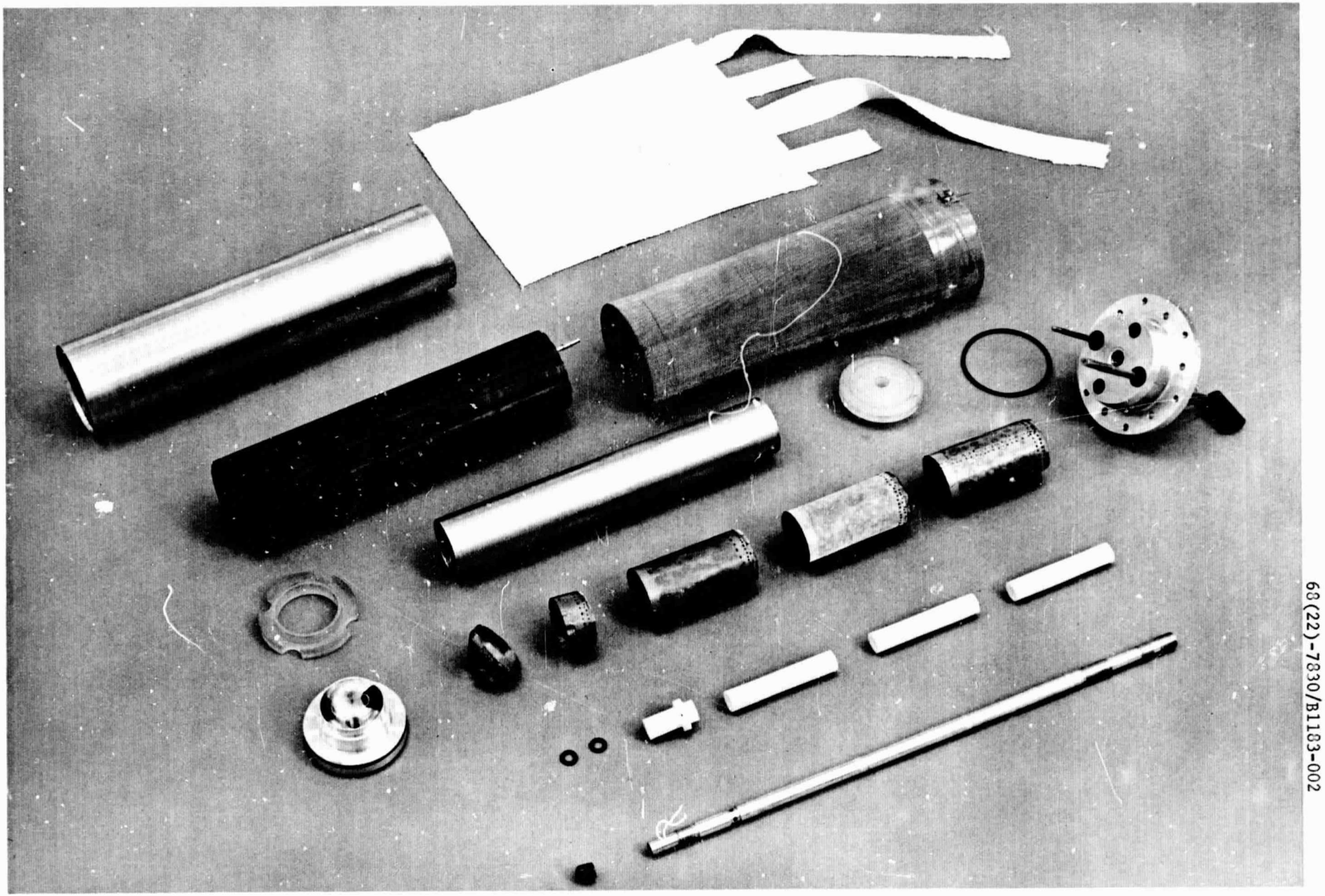

4-40 Flat Head screw
MS 9021-035 Oring
E.P.R.
Outer Shell
Anode
Cathode Screen
Inner Shell
Wick
Bottom Cap
MS 9021-035 Oring
E.P.R.
Cathode Connector Tab
Anode Connector
Revised Electrode Mounting
HS-209

FIGURE 4



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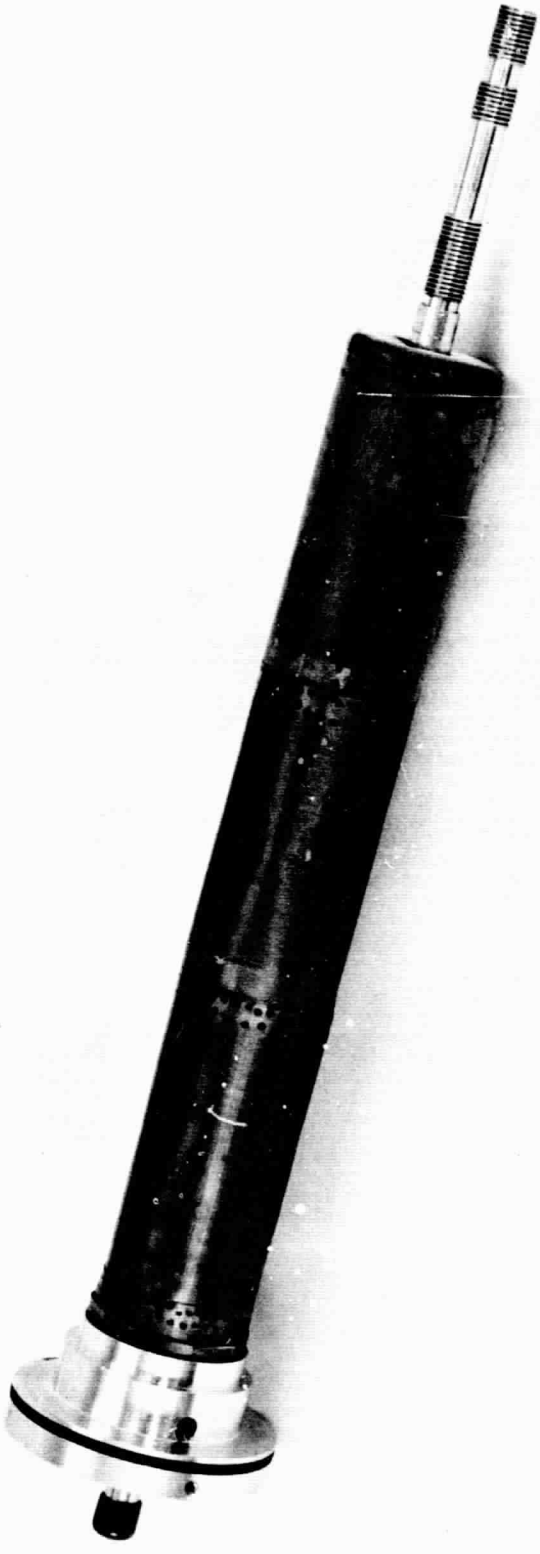


FIGURE 5

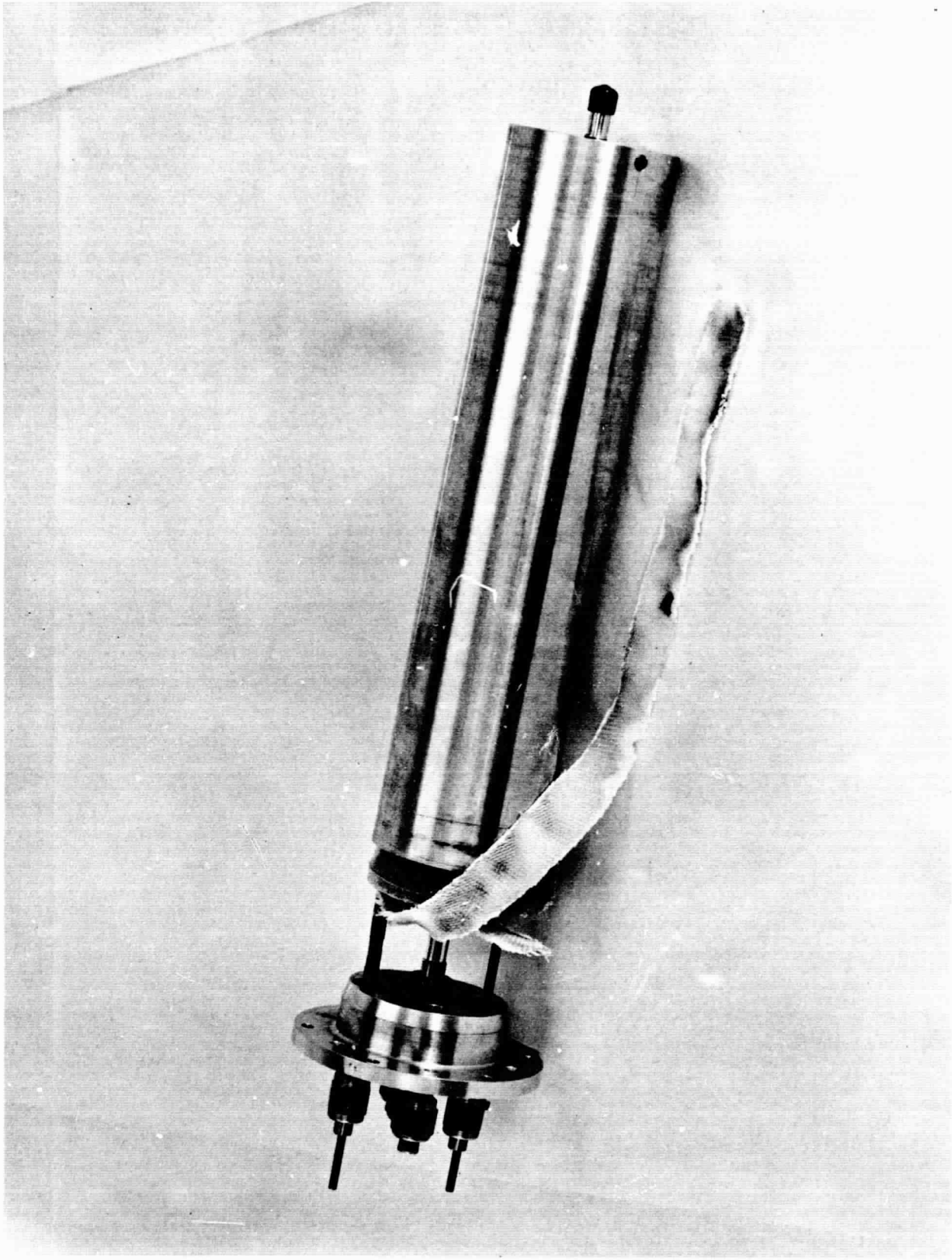
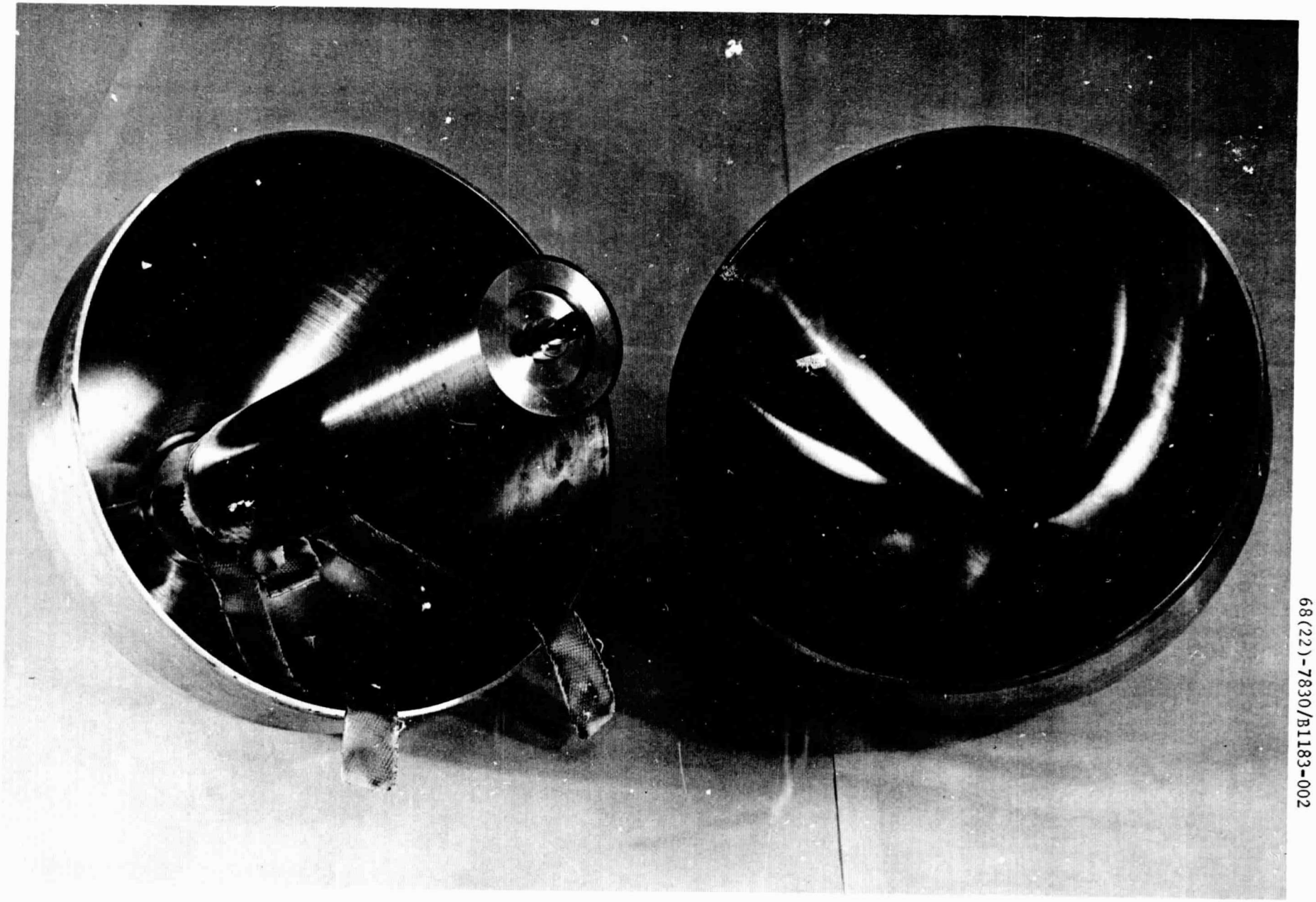


FIGURE 6

FIGURE 7



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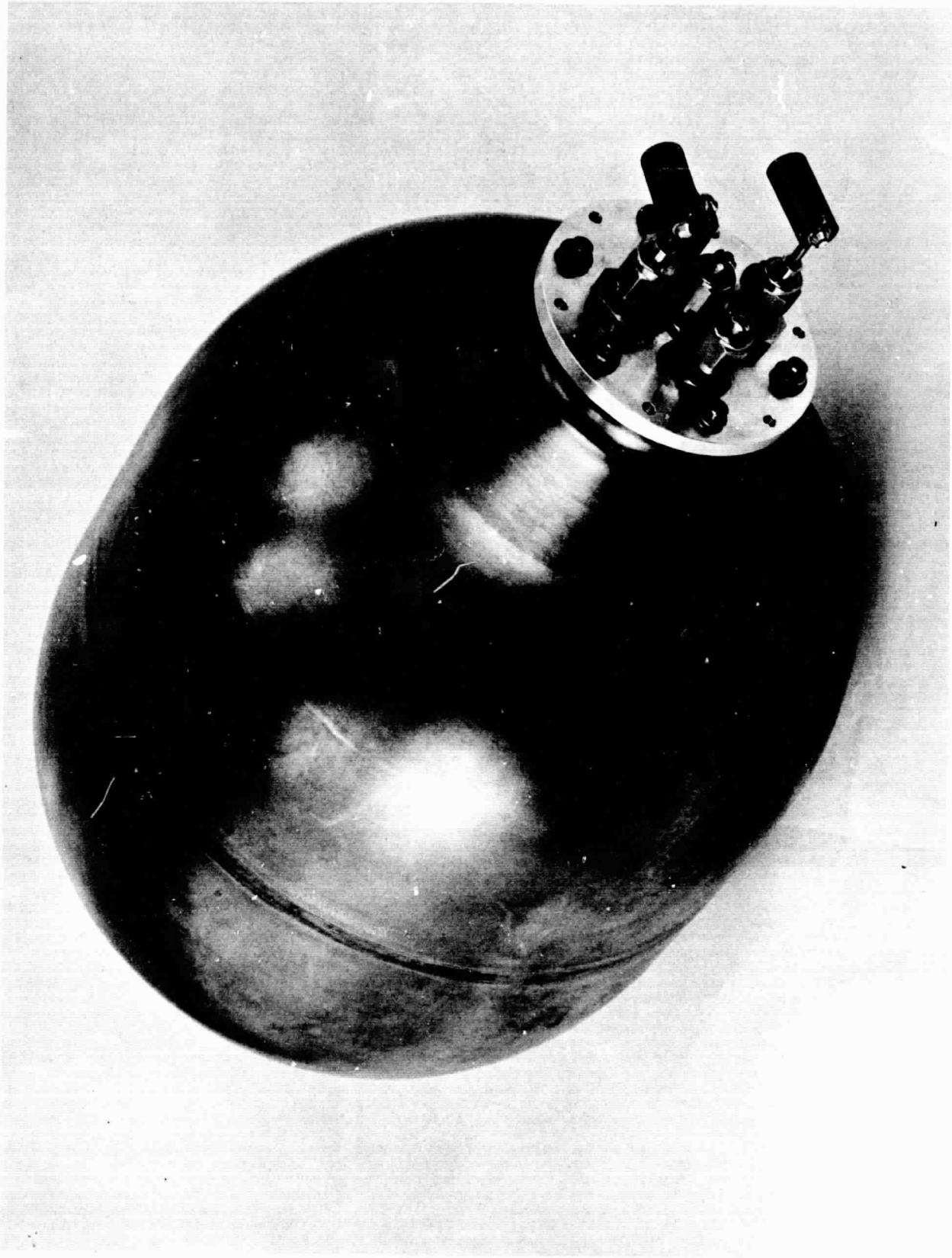
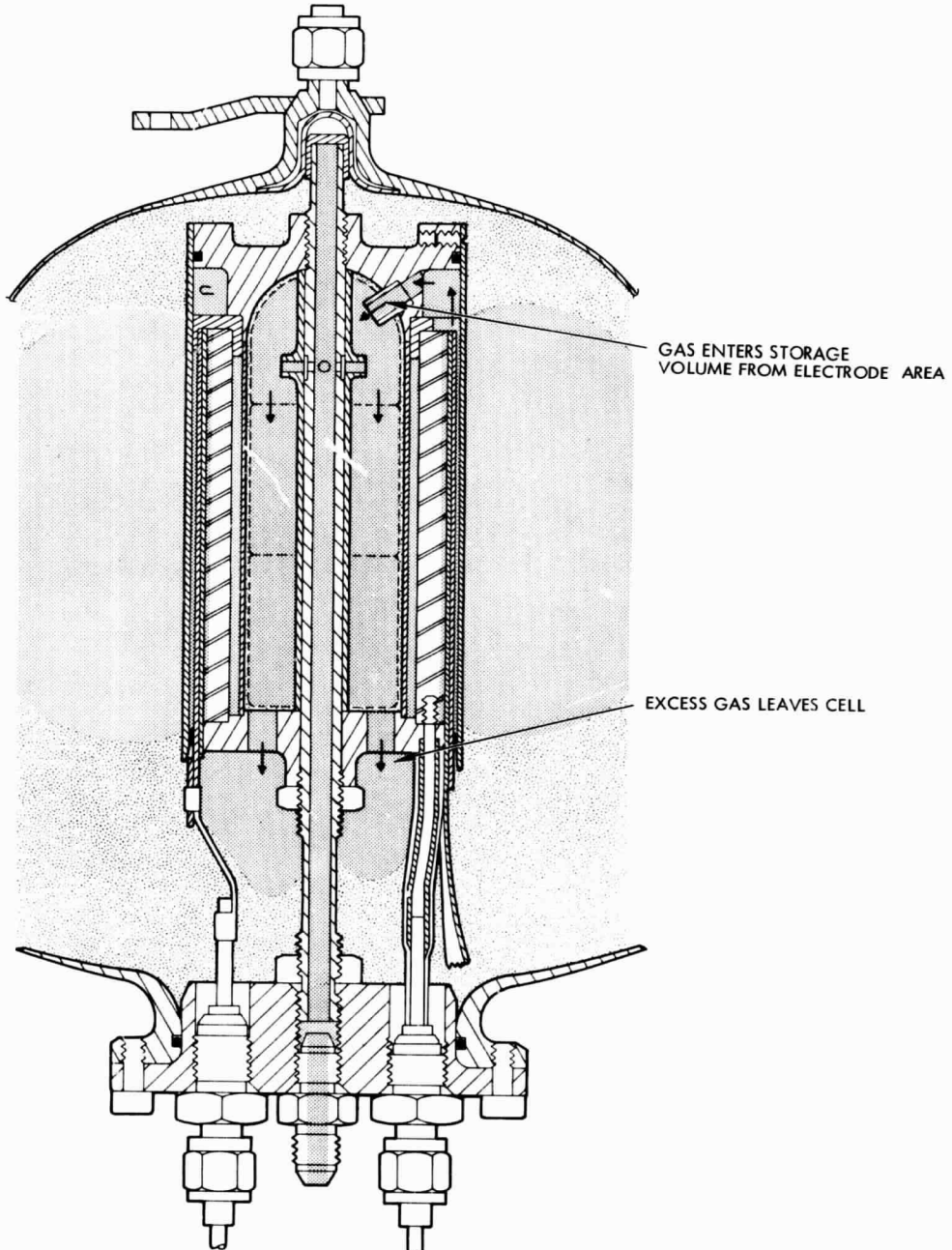
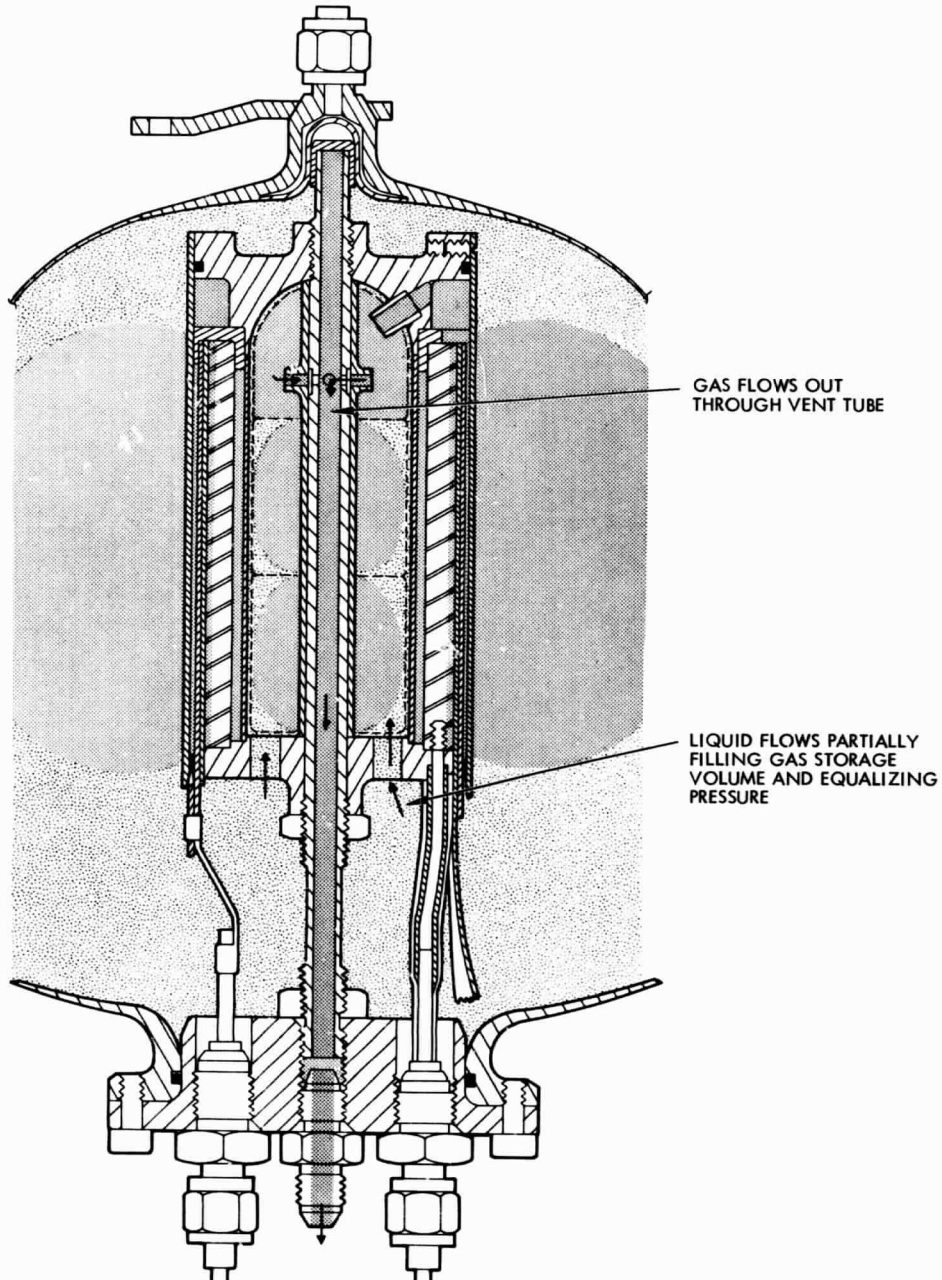


FIGURE 8

HYDRAZINE ELECTROLYSIS CELL DURING NORMAL GAS GENERATION



HYDRAZINE ELECTROLYSIS CELL DURING THRUSTING



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OPERATION (continued)

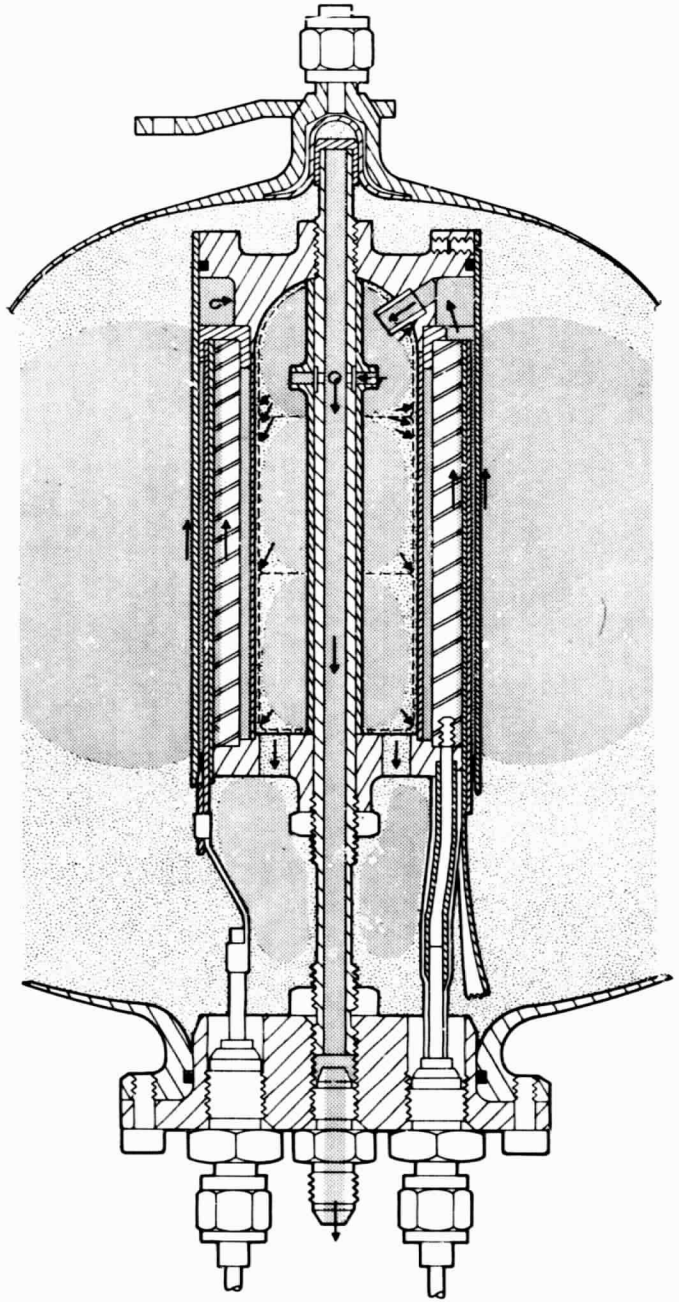
During gas thrusting, gas leaves the top screen compartment through the vent tube as shown in Figure 10. As gas is vented, pressure in the storage area falls and liquid or gas, depending on position of the ullage bubble in the tank, moves back into the storage area until the pressure is equalized. If liquid enters, it will tend to enter all compartments through the liner screen as shown. Also, if the pressure change is abrupt and fairly large, some liquid may move into the cell through the relatively higher impedance path offered by the wick. In design of the final system, the geometry will probably be such that gas, rather than liquid, is available at the cell outlet, thereby avoiding some of the complications occasioned by liquid flow.

If liquid does enter the gas storage compartments, either by entrained droplets from the electrode area, liquid flow following gas usage, or because it was there at the start of the mission, the gas compartments will be cleared automatically as shown in Figure 11.

Capillary action causes all screens to be wet with liquid. As generated gas enters the top compartment, pressure tends to rise and, if there is no liquid in the compartment, gas will not pass into the next compartment until the bubble break-through pressure (typically several inches of liquid head) is reached. Conversely, if liquid is present, it may move easily through the wetted screen at a very minute pressure differential. Because of these surface tension effects, each gas compartment will be emptied in turn before the next compartment is affected and all liquid will be expelled preferentially into the annulus along the shell wall and back into the main tank.

When bubble break-through does occur it is important that it be into the next compartment rather than the annulus. This is accomplished in the present design by using 10 micron screen for the wall liner and 25 micron screen for the dividers. As explained in the previous Task IV report, the fine screen is necessary only in order to test the device in adverse earth gravity; in space a screen mesh of about an inch would be adequate.

HYDRAZINE ELECTROLYSIS CELL EXPELLING RESIDUAL LIQUID AT START OF MISSION



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TEST PROGRAM

The main objectives of the tests conducted were to characterize the various operating parameters of a developmental model electrolysis cell and to demonstrate gas expulsion free from entrained liquid in both favorable and unfavorable attitudes with respect to earth gravity. The six major groups of tests were:

1. Initial checkout of fit and function
2. Design performance verification tests
3. Effect of temperature on operating parameters
4. Gas expulsion tests
5. Supplementary tests in investigation of specific problems
6. Life Test

The detailed test plan appears as Appendix A of this document and a summary of the tests performed is shown in Table I.

In addition to the data reported herein, a log was maintained which contains a complete description of each test and all data recorded. This log will be supplied to JPL with the final report.

INITIAL CHECKOUT

The first test to be conducted was verification of proper operation of the internal gas compartment screens. Before installation of the electrodes and outer shell, the assembly shown in Figure 12, was tunred upside down and the internal gas storage cavity, complete with screens, was filled with water. Air was then forced back through the vent port and water displaced from the gas compartments. Two tests showed expulsion efficiencies of 94% and 93%, respectively. The only liquid remaining in the assembly was contained with in the annulus between the liner screen and inner shell wall and the amount needed to wet the screens. This is the normal design operating condition and proved that liquid could be expelled against one gravity.

One interesting item was noted in this test. If the screens were dry it was not difficult to fill the internal cavity with water. However, it was almost impossible to force water into the gas compartments if the screens were first wet, as would be the normal system operating condition. This behavior would be expected to help avoid filling the gas storage area with liquid during launch sloshing or vibration.

Following check-out of the gas vent system, the complete electrode module was assembled for the first time and installed in the tank. The volume in the tank with the electrode module installed was determined by filling the tank completely with water and measuring its weight. The unit had previously been weighed before filling with water. The weight difference indicated an effective volume of 720 cubic inches.

TABLE I
TEST SUMMARY

TEST NO.	TEST DURATION, HOURS	TEMPERATURE, °F (RANGE DURING TEST)	PROPELLANT LOAD % FULL	ELECTROLYTE CONCENTRATION %	NOMINAL VOLTAGE VOLTS	NOMINAL CURRENT AMPS	REMARKS
653-3	2.0	74-77	90%	0.5%	1.25	1.4	(Functional checkout)
653-4	4.9	70-77	90%	0.5	1.25	1.4	
653-5	4.9	68-76	90%	0.5	1.50	2.5	
653-6	4.0	68-76	45%	0.5	1.50 1.75	1.9 2.9	
653-7	3.0	114-125	45%	0.5	1.50	2.6	High temp. test
653-8	4.8	39-40	45%	0.5	2.0	2.9	Low temp. test
653-9	4.0	56-63	90%	0.25	6.0 5.0	0.7 0.5	Cell dismantled
653-10	3.0	59-64	90%	0.25	2.5 5.2 6.2	0.4 0.7 0.8	
653-11	4.0	54-64	45%	0.75	2.75	4.4	
653-12	0.8	71-77	4%	10	5.0	0.5	Installed new wick
653-13	4.6	79-83	4.0	10	2.0	1.6	
653-14	5.1	66-72	Moist wick only	10	2.0	1.7-1.4	Run to dryness
653-15	46.1	54-74	Moist wick only	10	2.0	1.3-0.2	
653-16	28.3	60-94	30%	1.5	2.0 2.5	2.8-2.0 2.5-1.4	First gas vent. test
653-17	28.5	60-80	30%	1.5	2.5	2.5-0.4	No screens in gas compartment
653-18	31.5	70-90	30	1.5	2.5 2.0	3.0-2.5 2.0-1.5	Replaced screens, new wick. Installed plenum and orifice in gas vent line.

TABLE I (Continued)

TEST NO.	TEST DURATION, HOURS	TEMPERATURE, °F (RANGE DURING TEST)	PROPELLANT LOAD % FULL	ELECTROLYTE CONCENTRATION %	NOMINAL VOLTAGE VOLTS	NOMINAL CURRENT AMPS	REMARKS
653-19	7.4	74-94	30%	1.5	2.5	Variable due to gas venting.	Gas venting test.
653-20	7.6	72-94	30%	1.5%	2.5 2.0	Variable due to gas venting.	Gas venting with plenum.
653-21	6.5	70-93	30%	1.5%	2.5 2.0	Variable due to gas venting.	Gas venting with plenum
653-22	31.6	73-104	30%	1.5%	2.5	2.0-0.7	Gas venting with plenum.
653-24	7.1	68-88	30%	1.5%	2.5	1.4-0.4	Wick was rinsed and re-installed. No squeeze on wick. Current decay test.
653-25	23.1	65-83	45%	1.0%	2.5	2.0-0.7	Current decay test.
653-26	7.0	64-73	90%	0.5%	2.5	2.7-0.7	Current decay test.
653-27	4.0	65-75	90%	0.5%	2.5	2.8-0.4	Current decay test.
653-28	21.4	70-90	30%	1.5%	2.5	1.2-0.06	Test without wick
653-29	3.0	83-92	45%	1.0%	2.5	2.8	No wick ullage bypass valve open for first time.
653-30	28.9	74-87	90%	0.5%	2.0	2.5-2.3	No wick. Ullage valve open
653-31	77.3	64-104	30%	1.5	2.5	2.1-1.5	New wick installed. Cell in upright position

TABLE I (continued)

TEST NO.	TEST DURATION HOURS	TEMPERATURE, °F (RANGE DURING TEST)	PROPELLANT LOAD % FULL	ELECTROLYSIS CONCNETRATION %	NOMINAL VOLTAGE VOLTS	NOMINAL CURRENT AMPS	REMARKS
653-32	54.0	70-99	30%	1.5%	2.0 1.5	2.5-2.8 0.9-1.4	Cell in i verted po ition
653-33	48.2	70-95	30%	1.5	2.0 1.5	2.3-1.4 0.9-0.5	Cell on side position
		Total electrolysis test time at beginning of life test was 504.1 hours					
653-34			45%	1.0			Life Test

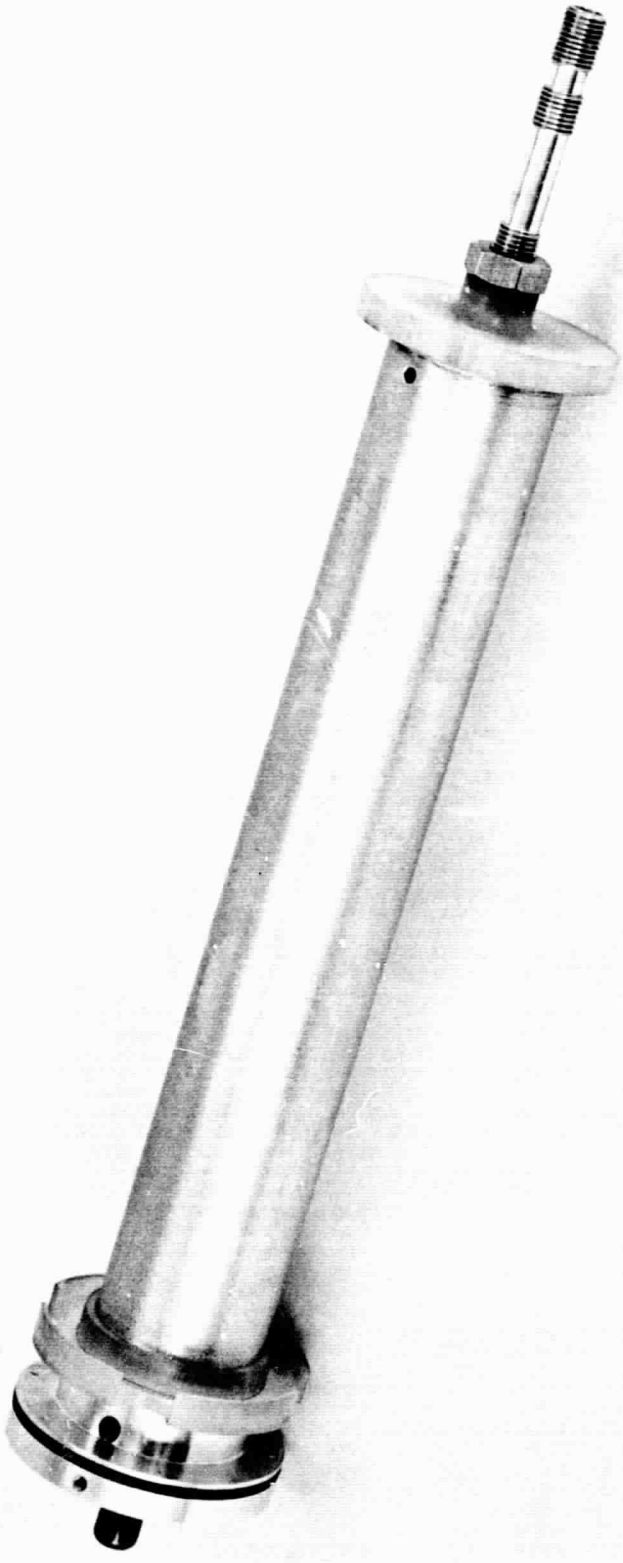

FIGURE 12

INITIAL CHECKOUT (continued)

The electrode module was removed from the tank, the flange again installed and the assembly subjected to a proof test at 400 psig and a leak test at 200 psi. The proof test consisted of filling the tank with water and then cycling the tank pressure three times from zero to 400 psig to zero. On each cycle the pressure was held at 400 psig for five minutes. Following proof test and leak test the tank was visually examined and found to have suffered no apparent damage.

The electrode module was disassembled for cleaning and passivation prior to the first series of tests. Cleaning and passivation was conducted in accordance with Hughes Document DP 30929-002, Processing Parts for Hydrazine Service, as required by the Test Plan. The electrode module was then re-assembled and installed in the tank. Electrical resistance measurements were made to determine that the anode and cathode were electrically separated and that the cathode was grounded to the tank shell. The tank was installed on the test stand and filled with neat hydrazine for passivation of the entire assembly. This hydrazine was left in the tank overnight.

TEST STAND

The electrolysis cell/tank assembly is shown installed on the test stand in Figure 13. The tank is located in a chamber which can be completely enclosed and temperature controlled for thermal environmental tests. The power supply is visible to the left of the test chamber in the photo. The tank is mounted in a frame which can be oriented in various positions for gas venting tests. The test set-up is shown schematically in Figure 14. As will be described later in the program, several modifications were made.

ELECTRICAL CHECKOUT

Before replacing the neat hydrazine used for passivation of the system, a small amount was expelled to provide ullage space and a voltage-current survey was conducted to obtain base-line data on the conductivity of hydrazine without added electrolyte. The data from this survey are plotted in Figure 15.

After completing the baseline voltage-current survey, the neat hydrazine was expelled from the tank and replaced with hydrazine containing 0.5% oxalic acid. The tank was loaded 90% full (10% ullage). A voltage-current survey was conducted with this propellant mixture and these data also appear on Figure 15.

The first electrolysis test was then performed with a nominal voltage of 1.25V. Current increased from 0.91 to 1.45 amperes over a period of 2 hours. After about one hour of operation it was concluded that the pressure in the tank was not increasing as rapdily as it should, and a leak was suspected. This was confirmed after a valve was closed to isolate the tank from the lines containing the burst disc, pressurization gas supply and vacuum source. After the valve was closed, the pressure in the tank started increasing in a normal manner. It was subsequently found that the burst disc contained a small hole. It was replaced and the system was found to be free of any other detectable leaks. At this point the system was considered acceptable for test.

FIGURE 13

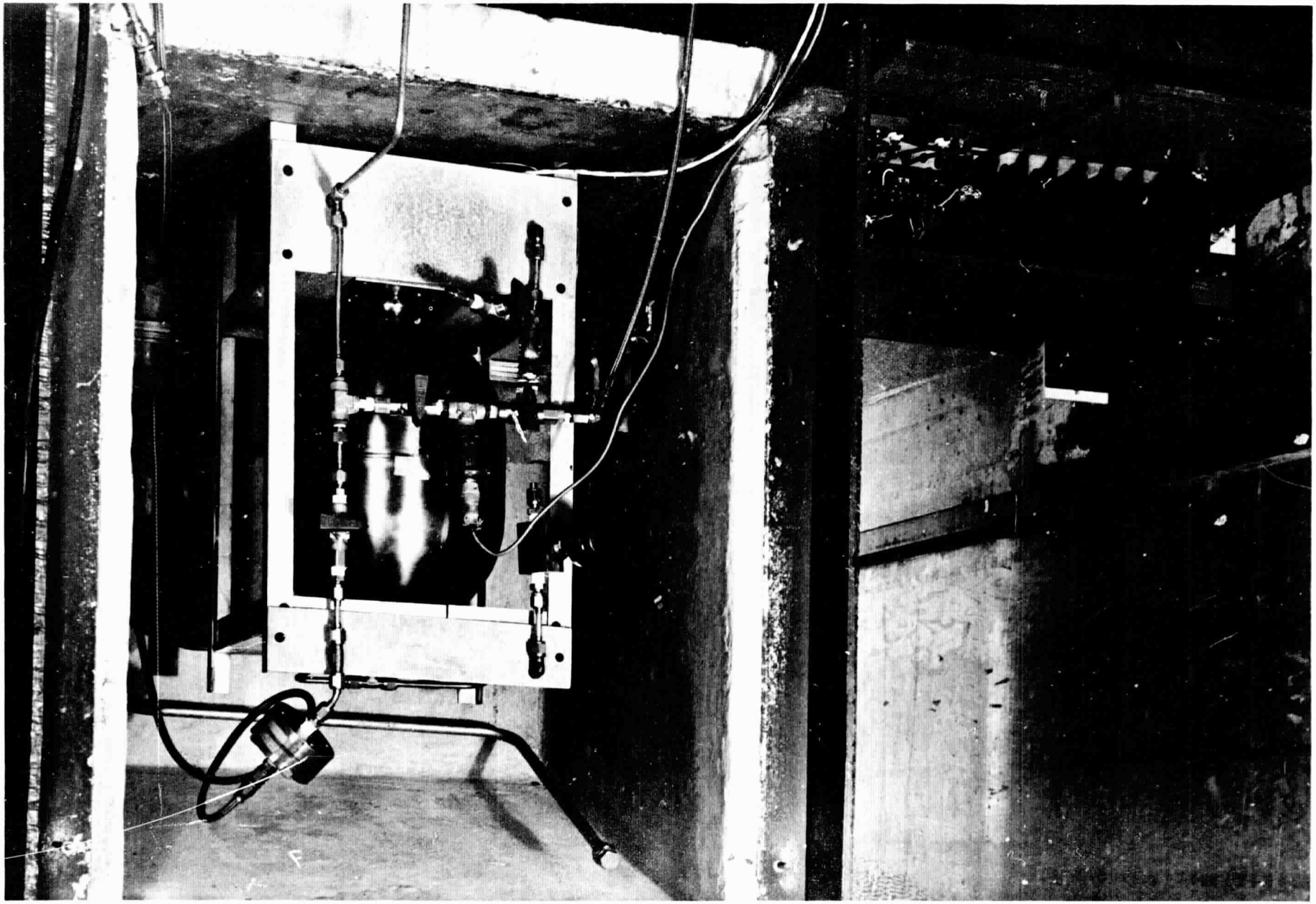

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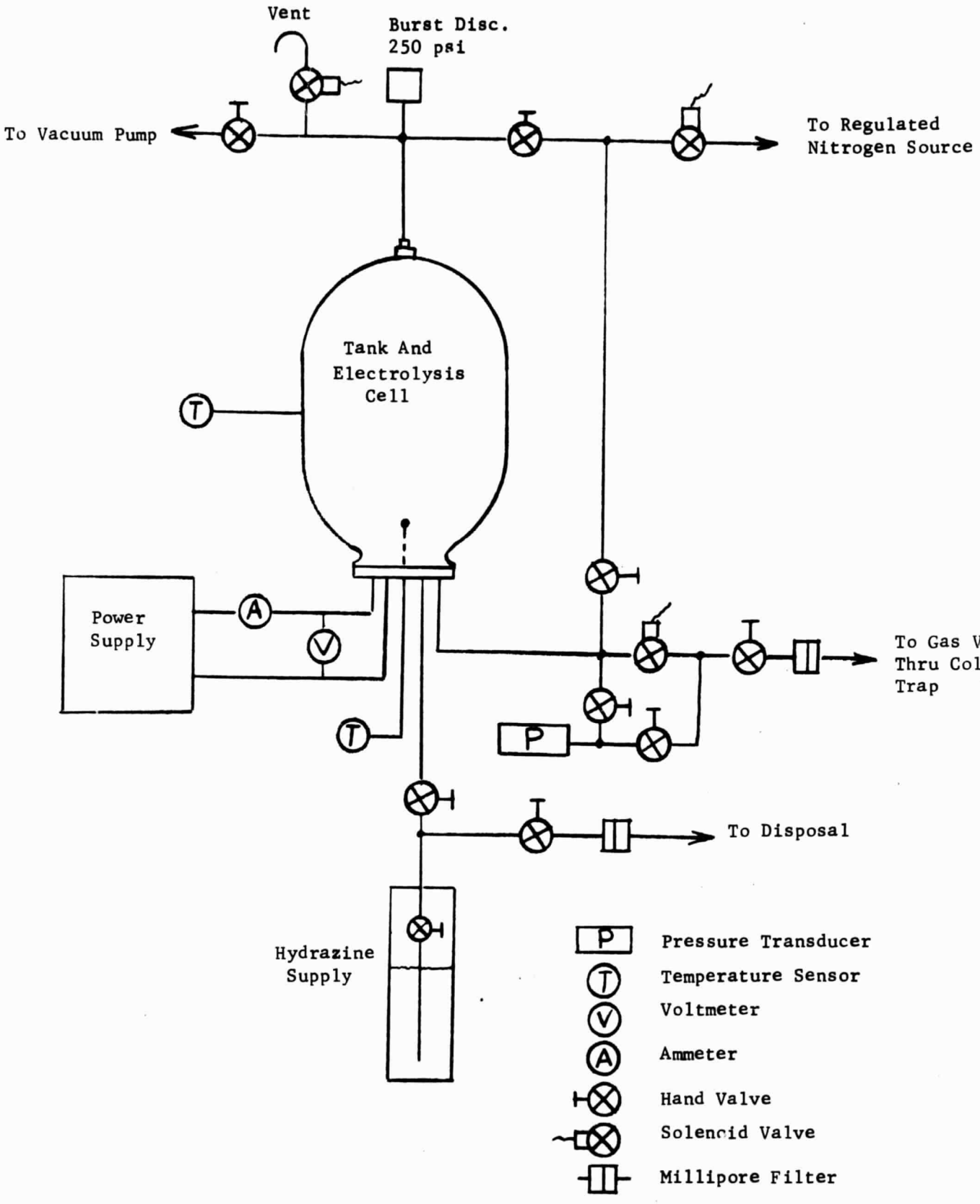
FIGURE 14



SCHEMATIC OF TEST STAND

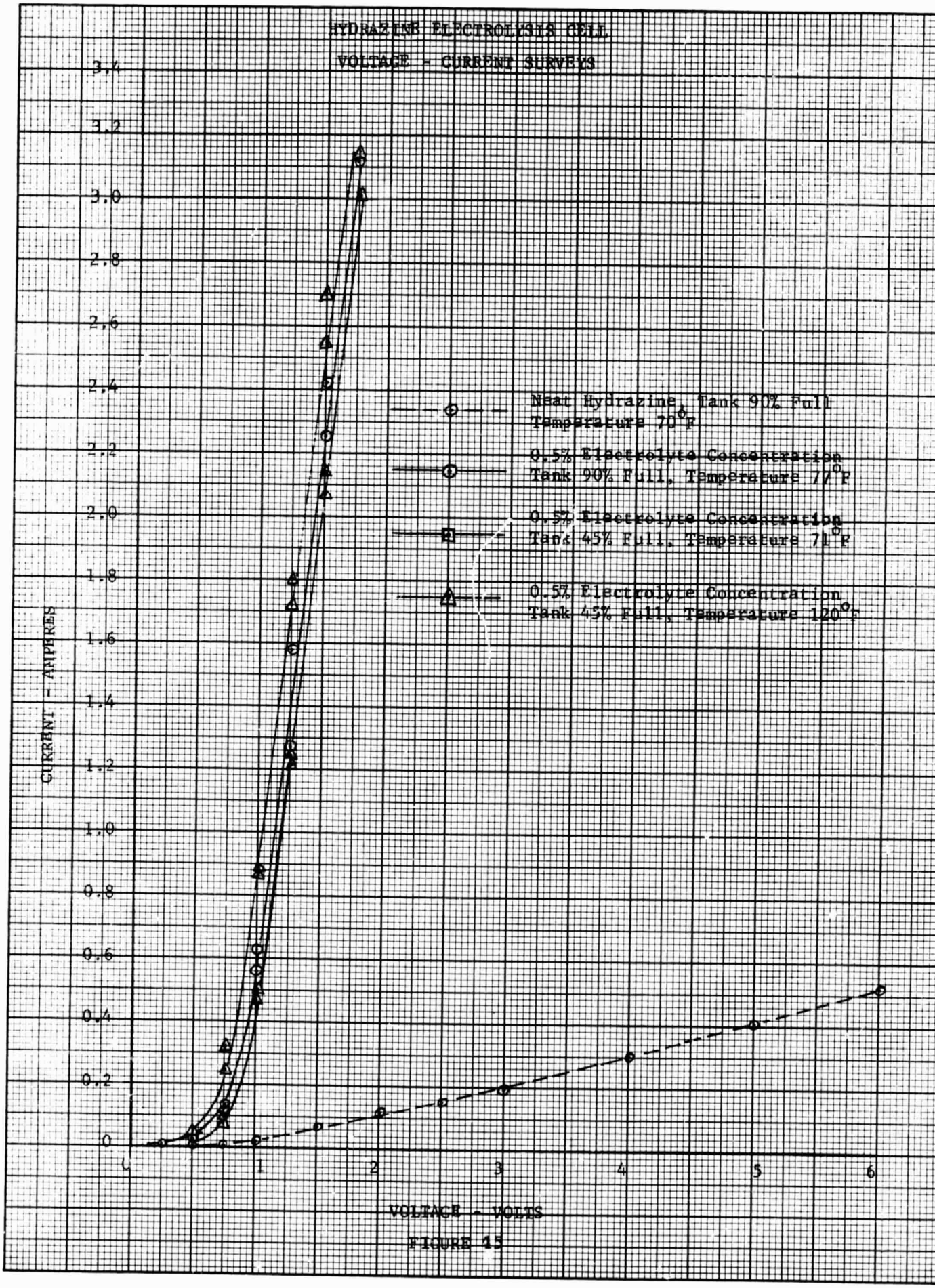


FIGURE 15

10 X 10 TO THE ½ INCH 359-12
KEUFFEL & ESSER CO. MADE IN U.S.A.

TESTS ACCOMPLISHED

653-4
653-5

Purpose:

Gas generating capability - cell conductivity.

These tests established a reference cell operating condition at 0.5% oxalic acid electrolyte and 90% full tank.

653-6

Purpose:

Gas generating capability - cell conductivity.

With electrolyte held constant and tank loading reduced to 45%, it was observed that conductivity of the cell also decreased. This is attributed to inability of the wick to maintain a uniform degree of saturation against gravitational force. When the amount of liquid between the electrodes is decreased less conduction takes place.

In zero gravity, the wick would be uniformly saturated and cell current would be expected to be independent ullage volume. In one gravity, however, a glass cloth wick will be less saturated the higher the distance above a liquid source because gravity begins to overcome surface tension forces in the larger pores. The result is a liquid gradient rather than a discrete height as observed in a capillary tube or uniform screen.

653-7

Purpose:

653-8

Effect of thermal environment measurement on gas generation rate.

These tests, conducted at +120°F and +40°F respectively, along with the ambient test 653-6, show that the cell has a gross (current) temperature coefficient of about 0.6%/°F. based on propellant temperature. The 4-5 watt thermal dissipation of the cell caused propellant temperature to be about 2 or 3 degrees higher than ambient.

All three tests were conducted with the same load of propellant and the same hardware. The only changes made from one test to the next were the environmental temperature and the applied voltage. The propellant tank was 45% full (11.76 lbs of propellant) and the electrolyte concentration was 0.5%.

For the high temperature and low temperature tests the tank was placed in an insulated enclosure. Heating was accomplished by forcing warm air into the enclosure from a heater-blower unit controlled by a thermostat which sensed temperature in-

side the enclosure. To cool the chamber for the low temperature test, liquid nitrogen was vented into the chamber through a thermostatically controlled valve.

At each of the three environmental temperatures, a survey was conducted to establish the voltage-current characteristics as a function of temperature. The data from these surveys are plotted in Figure 16. As would be expected, the current for a given voltage increases with temperature. The solid lines on Figure 16 represent the results of voltage-current surveys taken at the conclusion of each electrolysis test. Data obtained at the start was in very close agreement with that taken at the conclusion of the test except for the low temperature test. At low temperature the pre-test survey indicated lower current (dashed line on Figure 16) than the post-test survey which would imply that the internal cell temperature after several hours of operation was higher than indicated by the bulk propellant temperature. This would be expected as about 6 watts of power is being dissipated.

At each temperature, the cell was operated at a fixed voltage for a period of several hours. The data from these tests are shown in Figure 17, 18 and 19 where voltage, current and pressure are plotted as a function of time. Note that the voltage was intentionally changed in the middle of the ambient temperature test to obtain data at two voltages.

A comparison of gas generated with the theoretical amount, calculated on the basis of only hydrogen and nitrogen being produced at the rate of one pound per 1521 ampere hours, was made for five tests:

Test No.	Gas Generated % of Theory
653-4	94
653-5	95
653-6	101
653-7	113
653-8	99

It is clear that error from temperature gradients, variation in voltage and current, minor gas leaks and other sources do not allow these results to be conclusive in themselves. However, previous investigations including gas analyses, support the conclusions that electrolysis yields only the expected reaction products.

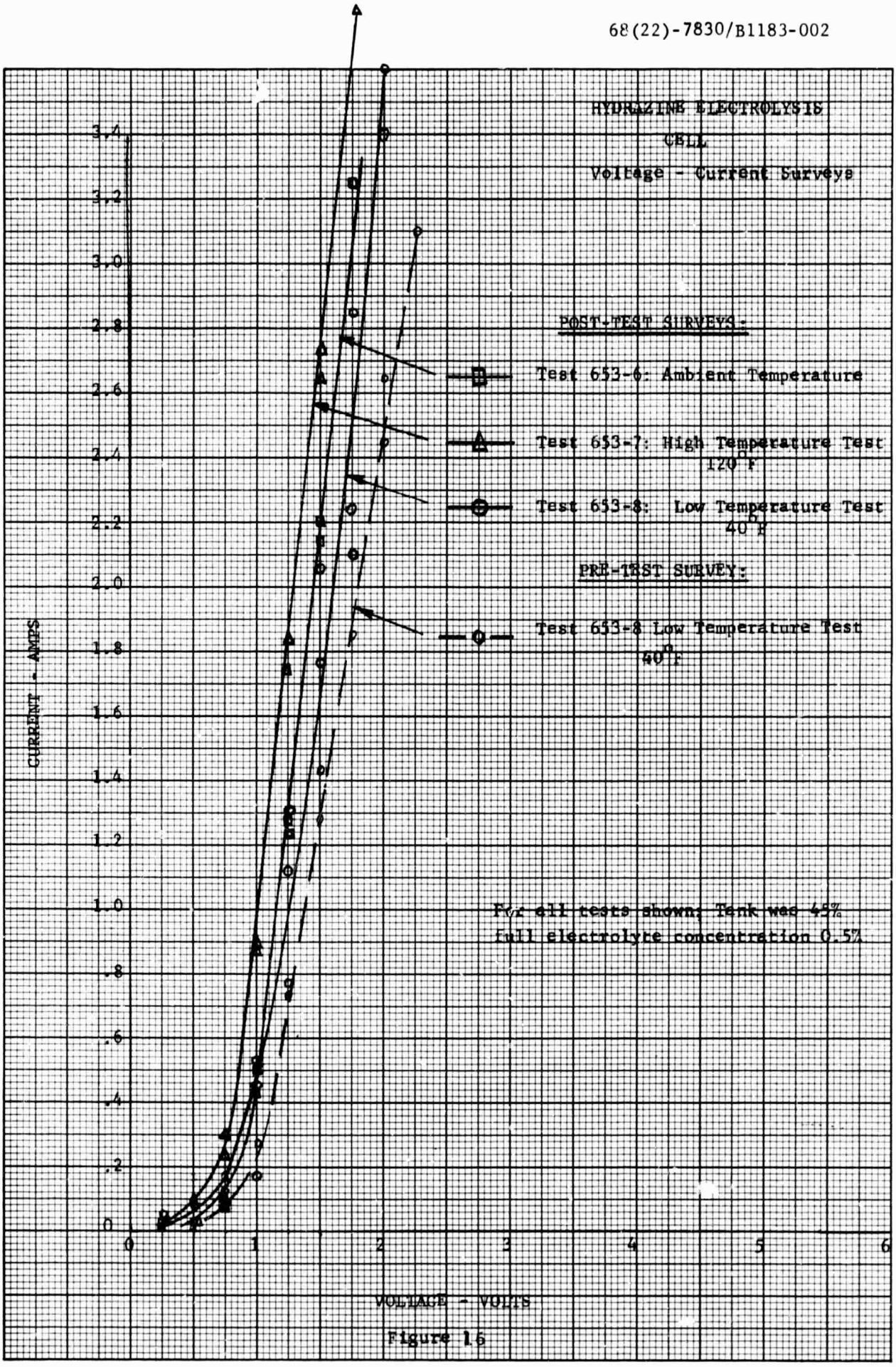


Figure 16

K&E 10 X 10 TO ½ INCH 46 1323
7 X 10 INCHES MADE IN U.S.A.
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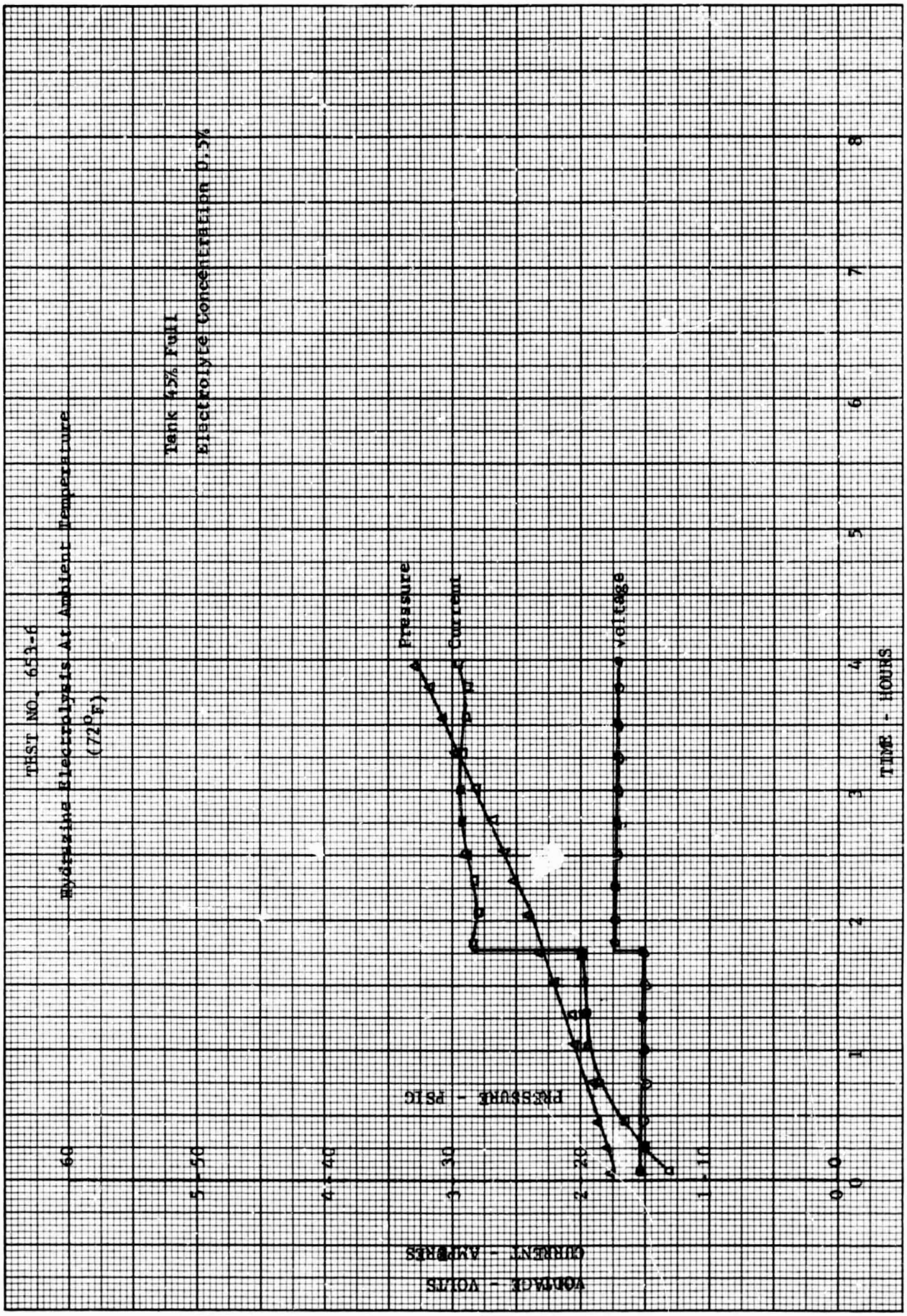
Hydrazine Electrolysis At Ambient Temperature
(72°F)
TEST NO. 653-6
Tank 45% Full
Electrolyte Concentration 0.3%
Pressure
Current
Voltage
PRESSURE - PSIG
CURRENT - AMPERES
VOLTAGE - VOLTS
TIME - HOURS
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8

FIGURE 17
-31-

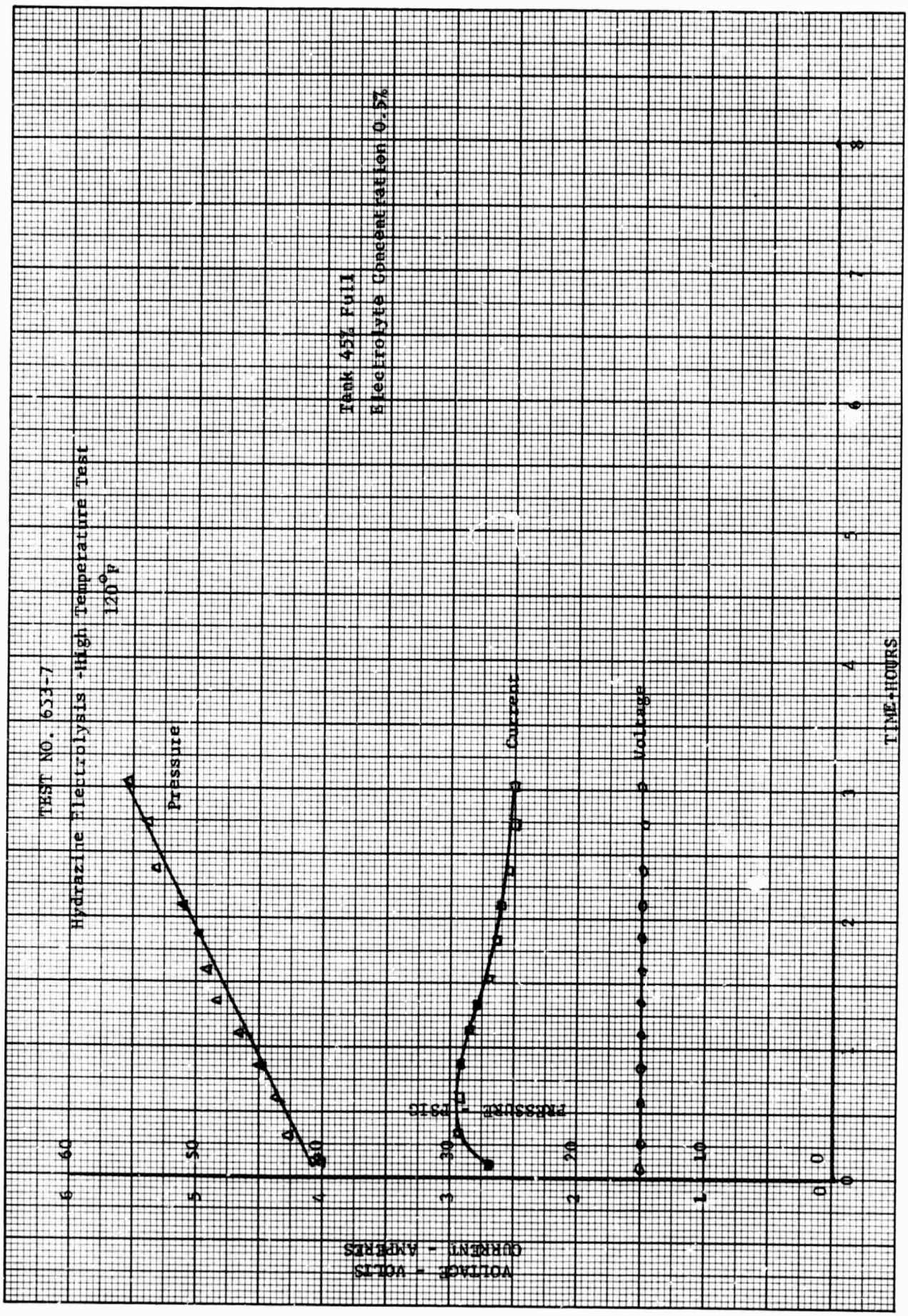
TEST NO. 633-7
Hydrazine Electrolysis -High Temperature Test
120°F
Tank 45% Full
Electrolyte Concentration 0.5%
Pressure
Current
Voltage
PRESSURE - PSIG
VOLTAGE - VOLTS
CURRENT - AMPERES
TIME-HOURS

FIGURE 18
-32-

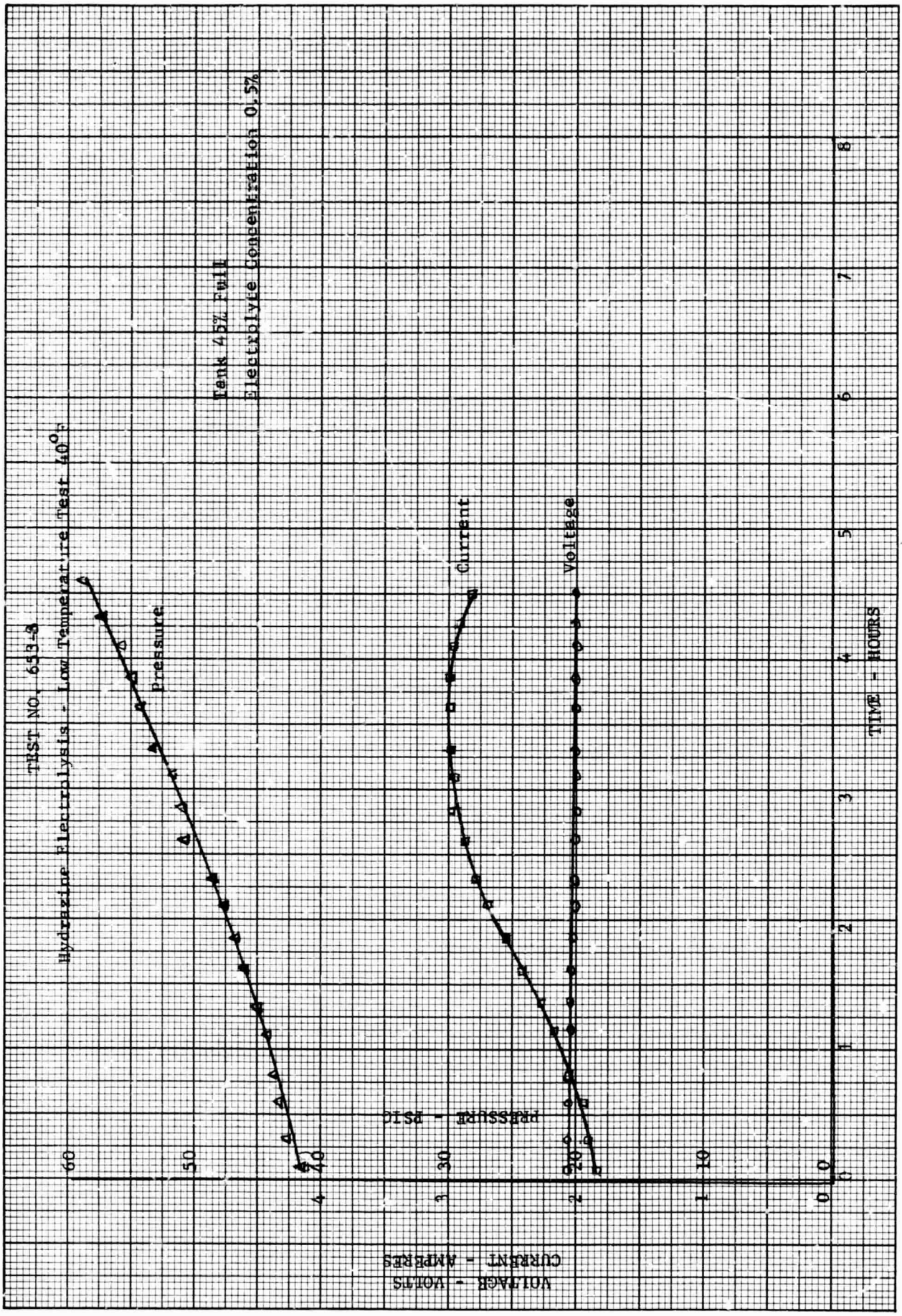

FIGURE 19
-33-

7 X 10 INCHES
KEUFFEL & ESSER CO.
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653-9 Purpose:

Effect of reduced electrolyte concentration.

In two tests where the oxalic acid concentration as reduced to 0.25%, conductivity was lower than expected. Table II shows the nominal currents observed for neat hydrazine, 0.25% and 0.5% oxalic acid.

TABLE II

Nominal Cell Performance at Three Electrolyte Concentrations, Ambient Temperature, 90% Full Tank

Electrolyte Concentration	Volts	Current, amps
0% (neat hydrazine) Test 653-1	1	.02
	2	.1
	4	.3
	6	.5
0.25% Oxalic Acid Test 653-9	5	0.5
	6	0.7
	2.5	0.4
	6.2	0.8
0.5% Oxalic Acid Test 653-3	1.25	1.4
653-4	1.25	1.4
653-5	1.5	2.5

In the previous laboratory study (Task IV) measurements of specific conductivity at various concentrations indicated that conductance of oxalic acid solutions is nearly proportional to the concentration. Thus conductance of a 0.25% solution should be approximately one-half that of a 0.5% solution rather than only slightly more than the neat hydrazine.

The reason for low conductivity in the present experiments has not been explained but is probably due to removal of ions from solution by some chemical reaction. It is not likely that an insoluble salt is formed by reaction with metals in the system because there have been no significant deposits observed. Further, the fact that a 0.25% solution either made by dilution of 0.5% solution (Test 653-9) or one made from fresh ingredients (Test 653-10) gave essentially the same results suggests that some impurity in the hydrazine might be responsible.

It is conceivable that hydrazine itself could reaction with oxalate first to form oxalic acid monohydrazide and then the dihydrazide. The first named compound would still be an electrolyte but the second would not. However, hydrazine oxalate is a stable salt as indicated by a sharp melting point and prepared solutions have been stored for some time without apparent loss in conductivity. The 0.5% solution of test 653-8 was, in fact, highly conducting over a period of several days but the first test with the diluted solution showed low conductivity. Likewise the fresh solution (653-10) had low conductivity very soon after preparation.

If a chemical reaction is truly the cause, then the lot of hydrazine used would have enough impurity to react with approximately 0.2% oxalic acid. This would mean the effective concentration of the 0.5% solution was only about 0.3% and the diluted solution about 0.05%. Ammonia is one known impurity present in an amount which could give the observed effect but it has not been established that a reaction (to form compounds such as oxamide) would occur under these conditions.

Reactions of the type described would appear to be insignificant regarding satisfactory operation of the system and conductivity may be restored by addition of only a very small amount of excess oxalic acid.

Following the first electrolysis test with 0.25% electrolyte concentration, the cell was dismantled for inspection. At this time it had accumulated 27.6 hour of electrolysis time. The following items were observed during examination of the cell components:

a) A light gray discoloration was found on the surfaces of the flange which were exposed to the propellant. It is believed that discoloration was caused by residual amount of Electrofilm Teflon solid lubricant which had been used previously on the flange for freeing a galled thread. Most of this discoloration was removed by polishing, but a small patch was left for purposes of further observation. This small patch subsequently disappeared during further operation of the cell. The gray discoloration is not considered to be significant.

b) The inner shell (1.5 inch diamter tube), which is mounted concentrically inside the anode and forms the enclosure for the gas compartment, had a yellow stain on its outside surface upward about 2.5 inches from the lower end of the part. The upper end of this stained area is at about the level of liquid external to the cell with a 45% propellant load and liquid could have reached the same level in the space between the anode and inner shell. It is believed that the inner shell acted as a secondary cathode (it was electrically connected to the cathode) and this discoloration was the result of

surface action during the high temperature test. The stain was removed by polishing, for a small patch which disappeared during the next test never reappeared.

c. All other parts were in excellent condition with no evidence of corrosion, incompatibility or other problems. The cell was reassembled using all the same parts including the same wick.

653-11 Purpose:

Effect of increasing electrolyte concentration.

To obtain data with a higher concentration of electrolyte, a test was conducted with the tank 45% full of propellant having 0.75% electrolyte concentration. A voltage-current survey was conducted before and after an electrolysis test of 4.0 hours duration. The data recorded during this electrolysis test is of doubtful validity because it was later determined that the electrolysis cell cathode must be grounded to the test stand in order to record correct current and voltage with the equipment used. The cathode had been left ungrounded because of the possible confusion in effective cathode area as noted above.

However, the voltage-current survey data were valid since different equipment was used. These data were obtained with a voltmeter and clip-on ammeter connected directly to the electrolysis cell. The survey data are plotted in Figure 20 along with a curve of current from a previous test with the tank 45% full of propellant containing 0.50% electrolyte. It will be noted that the higher electrolyte concentration resulted in the lower current in this cell. Although there was 21°F difference in temperature between these two sets of data, the temperature effect should not be greater than the effect of electrolyte concentration. This was the first strong indication that a problem in wicking action might exist.

653-12 Purpose:

Further study of electrolyte and wicking effects.

To obtain insight into the effects of electrolyte concentration and liquid level in the tank, an additional test was performed with 10% electrolyte concentration and the tank only 4% full. With this amount of propellant in the tank, the liquid level was well below the electrodes so that the liquid could only reach the electrode area by means of the wick. The results of a voltage-current survey showed very low conductivity; only slightly greater than with neat hydrazine. This is shown in the lower curve of Figure 2.1.

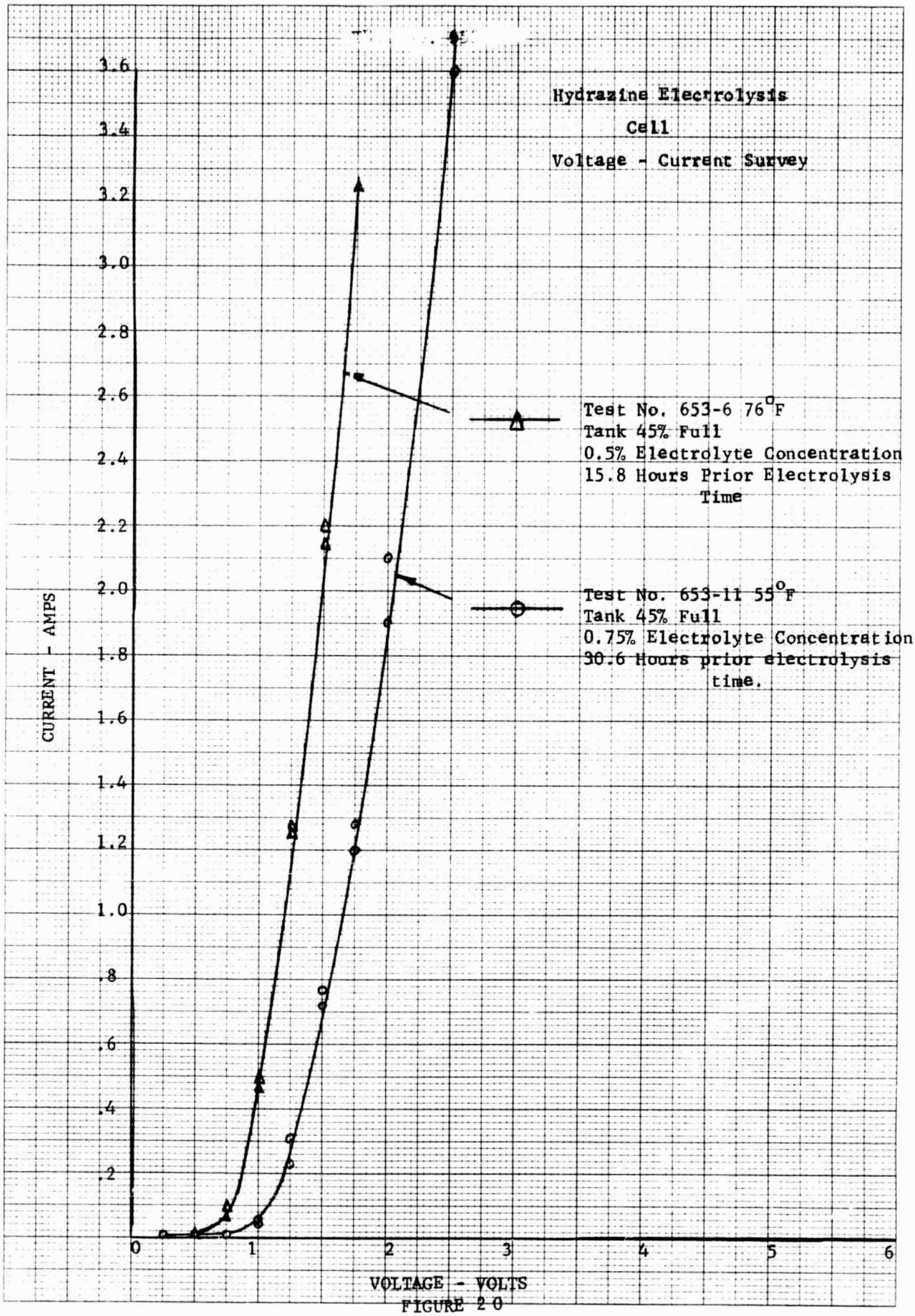
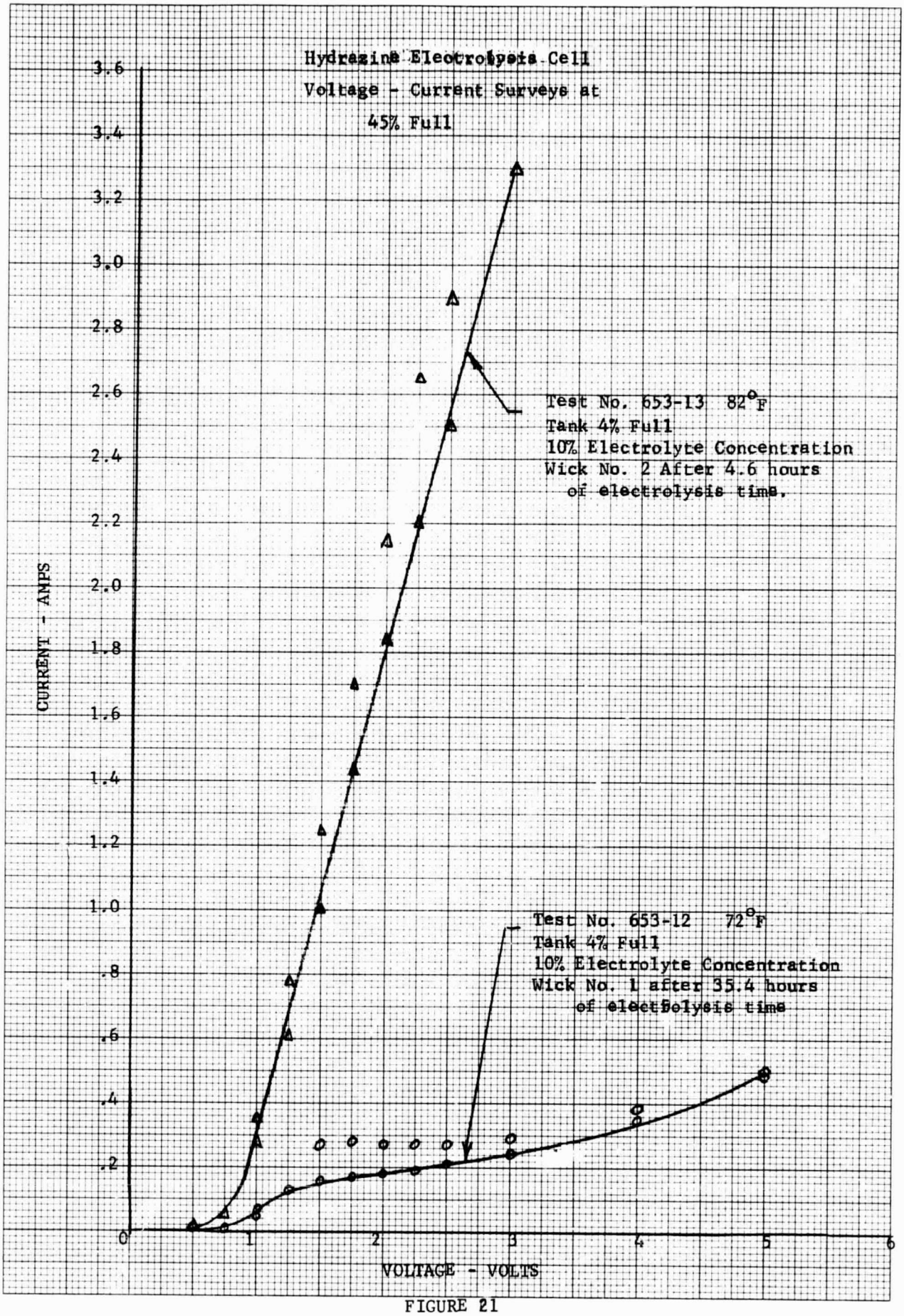

Hydrazine Electrolysis
Cell
Voltage - Current Survey
Test No. 653-6 76°F
Tank 45% Full
0.5% Electrolyte Concentration
15.8 Hours Prior Electrolysis
Time
Test No. 653-11 55°F
Tank 45% Full
0.75% Electrolyte Concentration
30.6 Hours prior electrolysis
time.
CURRENT - AMPS
VOLTAGE - VOLTS
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
1
2
3
4
5
6

FIGURE 20



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NO. 340R-10½ DIETZGEN GRAPH PAPER
10 X 10 PER HALF INCH

FIGURE 21

At this time it was suspected that the wick was no longer functioning properly. To verify this, the electrolysis cell was dis-assembled and a new wick was installed. Nothing unexpected was observed when the cell was dismantled. All parts still appeared to be in excellent condition. The wick was slightly moist at the top, with a greater amount of liquid in the lower portion.

653-13 Purpose:

Investigation of wicking rate.

After re-assembly with a new wick the cell was re-installed on the stand. In order to observe the wicking rate of the new wick, voltage was applied to the electrodes before loading any propellant into the tank. Then when propellant was loaded, the current increased as liquid was drawn up into the dry wick. After about 2.0 hours the current had reached a maximum of 1.86 amperes. The time history of this test is shown in Figure 22. After 4.6 hours, the test was terminated and a voltage current survey was conducted, the results of which are shown in the upper curve of Figure 21.

This test proved to be misleading in that it appeared to show that some sort of deterioration of the wick was being experienced. It was later shown that pressure differentials account for most of the problem. In fact, visual and microscropic examination has failed to show any sort of physical or chemical changes in the various wicks used. Also, it is noted that wicking rate, as shown by the time to reach equilibrium current, is many times greater than that required to resupply the liquid electrolyzed.

653-14
653-15 Purpose:

Electrolysis to dryness

To simulate conditions at the end of a mission where all the propellant may have been electrolyzed, a test was conducted in which it was attempted to run the cell to dryness. The cell was first operated for one hour at 2.0 volts to establish a stable operating condition with the tank 4% full of propellant of 10% electrolyte concentration. The propellant was then drained from the tank while the electrode potential was held at 2.0 volts. With only the propellant contained in the wick, electrolysis was continued for an additional 50.7 hours before the test was terminated. During this period of time, the current decreased from 1.6 amperes initially to 0.2 amperes in a smooth gradual manner with no sudden changes of current. The time history of this test is plotted in Figure 23.

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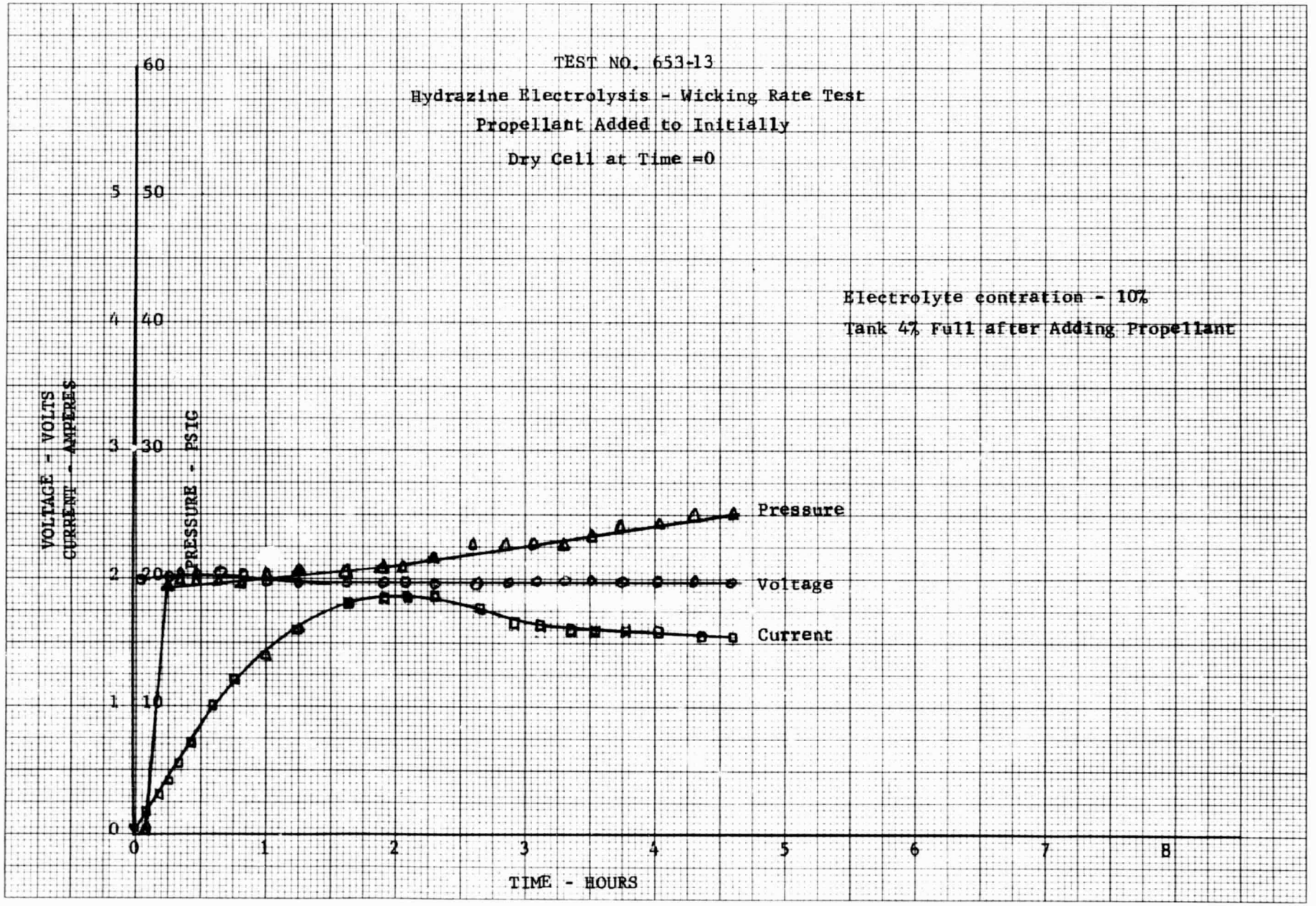

FIGURE 22

68(22)-7830/B1183-002

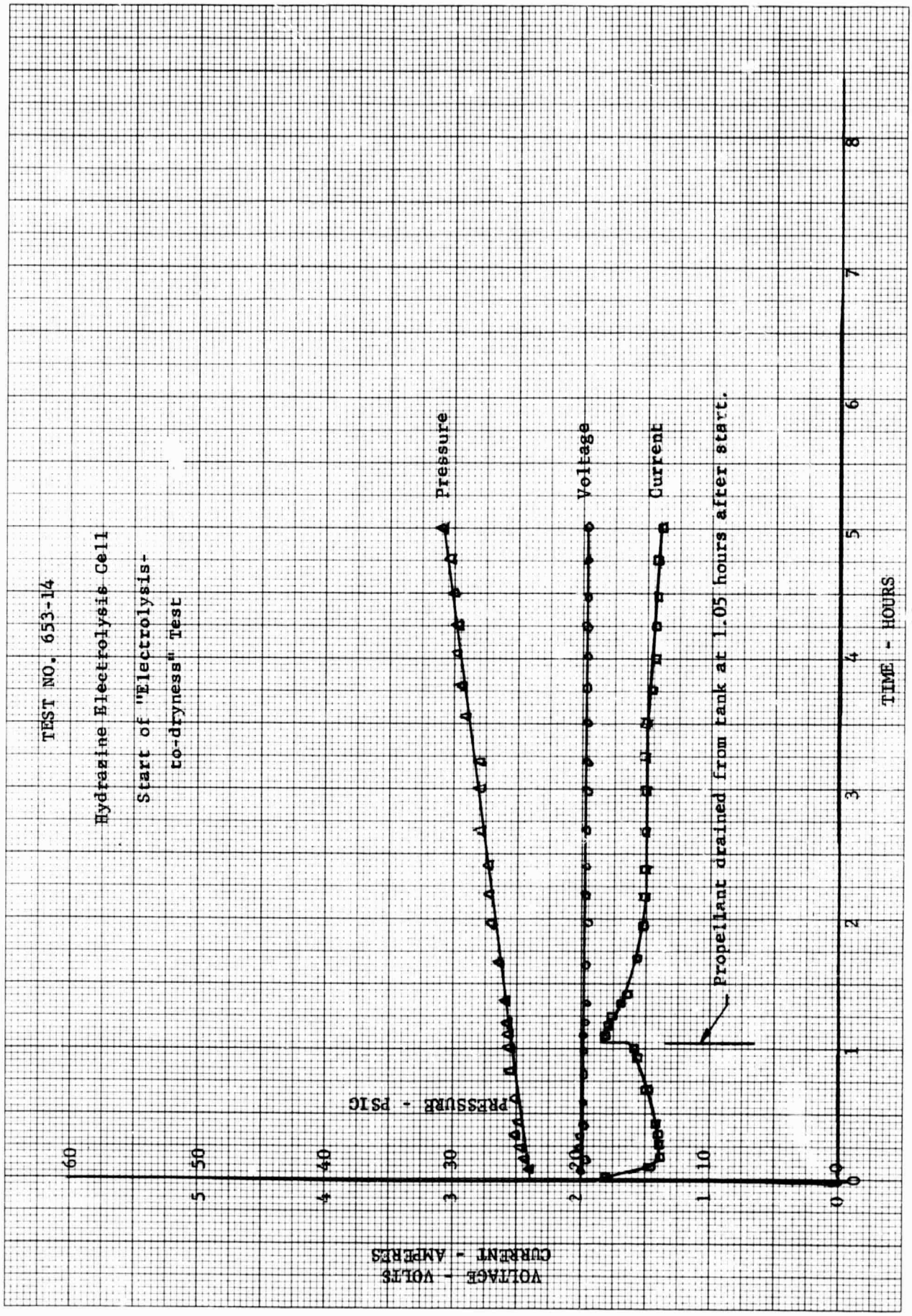

Figure 23a

10 X 10 PER HALF INCH
MADE IN U. S. A.

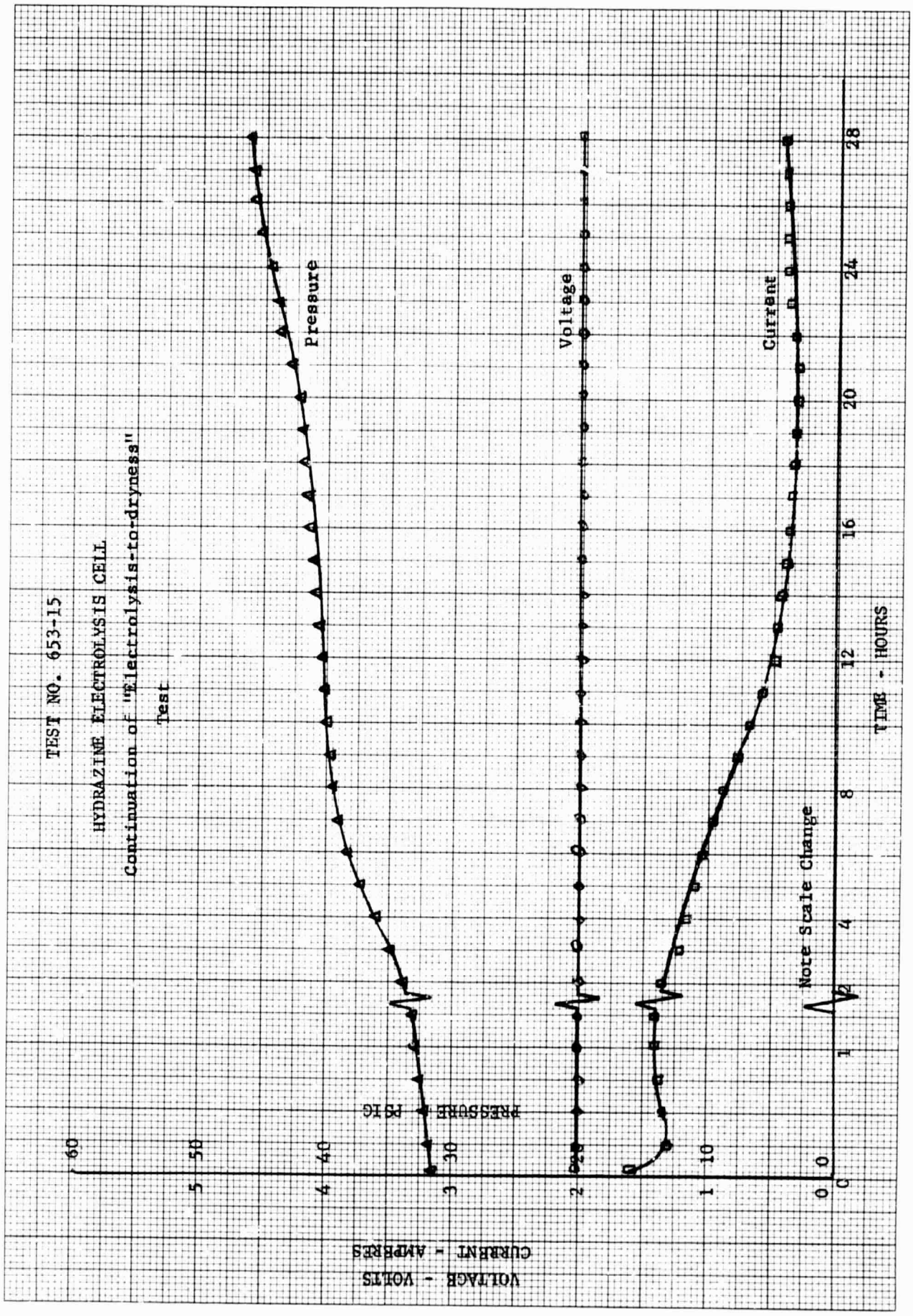

Figure 23b (Page 1)

NO. 340R-10½ DIETZGEN GRAPH PAPER
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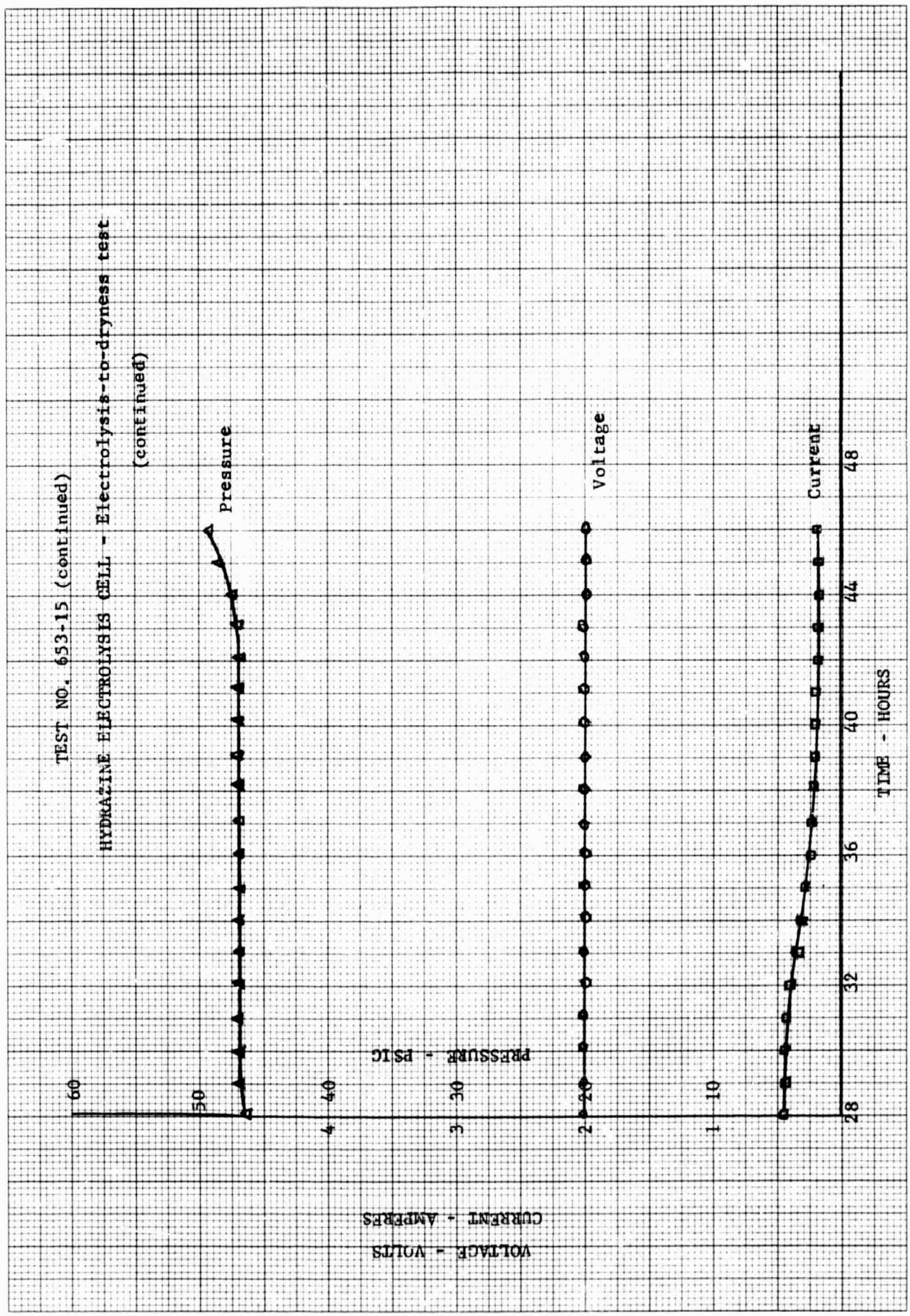

Figure 23c (Page 2)

NO. 340R 10½ DIETZGEN GRAPH PAPER
10 X 10 PER HALF INCH
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MADE IN U. S. A.

Following termination of this test, the electrolysis cell was dismantled for inspection. It was found that a small amount of propellant had remained in the bottom of the tank below the level of the drain fitting and that the wick was drawing propellant from this area into the inter-electrode space. This would explain the long gradual decrease in current observed in contrast to a rapid decay as the wic k became dry.

The wick was found to be still slightly moist even at the top, with a greater amount of liquid in the lower portion. The tails, which extended to the bottom of the tank, were quite wet with propellant. There was a deposite of while crystalline material on about 20% of the surface of the anode. This presumably was oxalate which normally would migrate to the anode surface and be precipated as dryness was approached. All parts appeared to be in excellent condition.

653-16 Purpose:

Gas venting demonstration.

The electrolysis cell was installed on the test stand in the upright position for the first gas venting tests and was filled to 30% capacity (7.84 pounds) with propellant of 1.5% electrolyte concentration. The gas outlet port on the tank flange was connected to a solenoid valve and orifice which simulated a gas thruster. The orifice size was selected to give the same flow rate as six 0.020 lbf thrusters firing simultaneously with a specific impulse of 120 lbf-sec per lbm. This would represent the highest flow rate condition expected for a flight system based on the mission parameters prescribed in the Technical Direction Memorandum dated May 20, 1968. The resulting flow rate is 0.001 lbm/sec and requires an orifice diameter of 0.035 inch for a supply pressure of 75 psia and gas temperature of 80°F.

A cold trap was connected downstream of the orifice to freeze any liquid which might be entrained in the gas. The cold trap was maintained under a vacuum of approximately 20 inches of mercury by means of an aspirator.

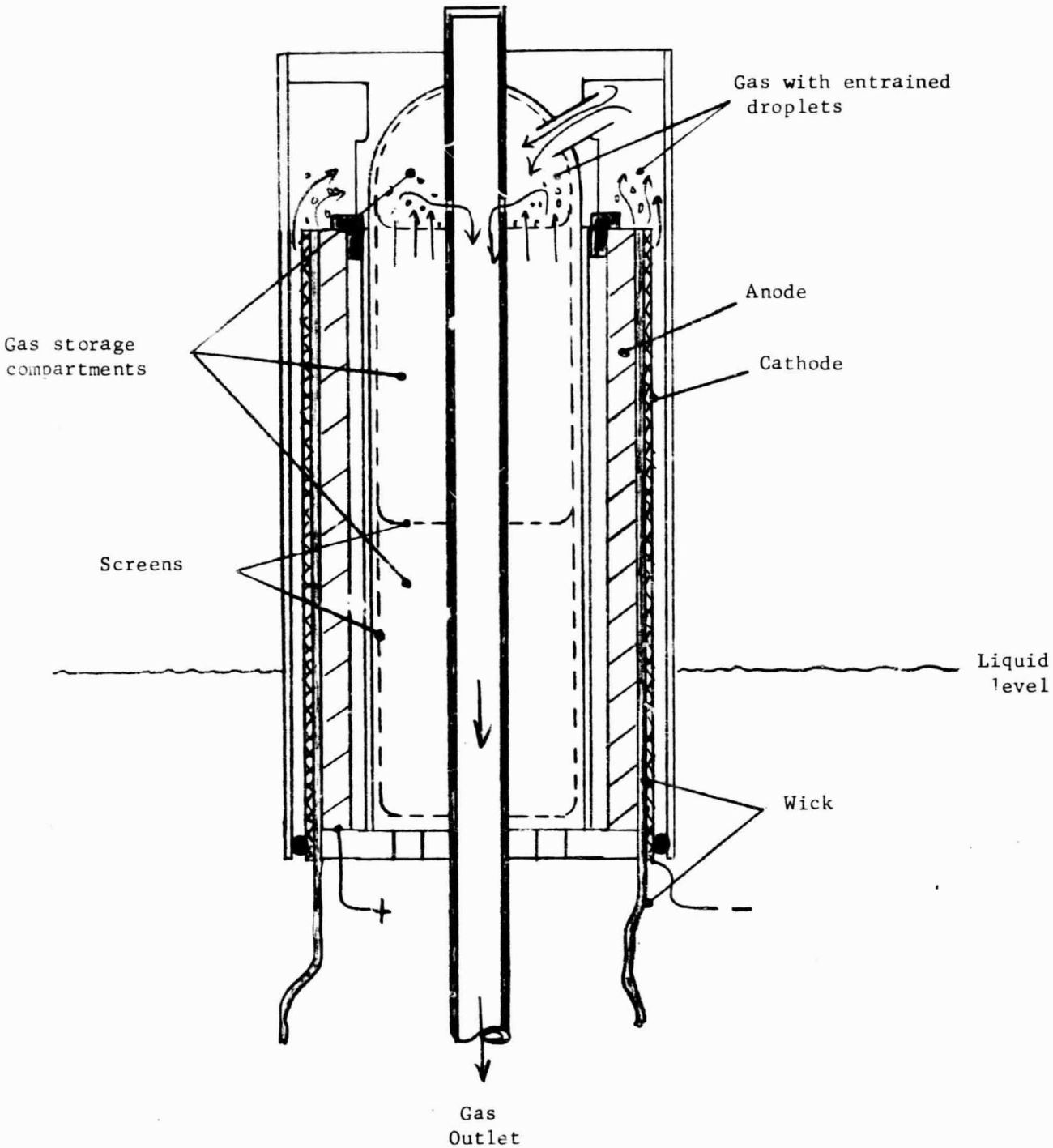
By analysis it was determined that the entire volume of the central gas compartment within the electrolysis cell would be vented in one second if the solenoid valve were to remain open. Therefore, all venting of gas from the cell was accomplished in pulses of either 0.050 second or 0.200 second. Time was allowed between pulses for gas generation to expell the liquid which would be expected to enter the gas compartment as pressure equilibrium was re-established.

The pulses were longer than the nominal 0.020 sec attitude control pulses expected for a flight system in order to demonstrate capability in excess of the nominal requirements.

During the first gas venting test, two significant phenomena were observed. First, it was noted that a fog appeared in the cold trap as the gas passed through. Examination of the cold trap after several pulses of gas revealed several drops of hydrazine frozen in the trap. The second phenomenon observed was that the current increased suddenly when gas was vented from the tank. In some cases, the current would more than double within about five seconds after pulsing, then slowly return to its initial value.

These two phenomena may be explained by consideration of the transient behavior of the liquid and gas within the electrolysis cell as a portion of the gas in the storage compartment is suddenly vented. With the solenoid valve open, gas flows out of the top section of the gas compartment first, as shown in Figure 24, thus creating a pressure differential across the screen partition separating the top section from the next lower section of the gas compartment. Because of the small volume of the top section, even a short pulse results in a large pressure change (e.g., 20 psi) and hence, the pressure differential across the top screen partition greatly exceeds the bubble breakthrough pressure of the screen. The 25 micron openings in the screens are normally filled with liquid by capillary action. As the bubble breakthrough pressure is exceeded, gas from the second section of the gas compartment breaks through the screen partition forcing liquid out of the screen openings. The liquid droplets formed could be entrained in the outflowing gas. However, the next experiment showed this explanation is only partly correct.

The current increase which followed gas venting may be explained by further consideration of transient pressure differences within the electrolysis cell. Since the top section of the gas compartment is connected through a transfer port to the annular space above the electrodes (See Figure 24), a sudden drop in storage compartment pressure is also experienced in the area surrounding the electrodes. This creates a pressure difference between the electrode cavity and the main tank volume which causes liquid to flow in from the tank through the wick. The wick then contains more fluid than normal capillary action provides. This, in effect, increases the amount of electrolyte within the inter-electrode space and results in increased current flow.



FLOW PATH DURING GAS EXPULSION

Figure 24

653-17 Purpose:

Investigate liquid entrainment

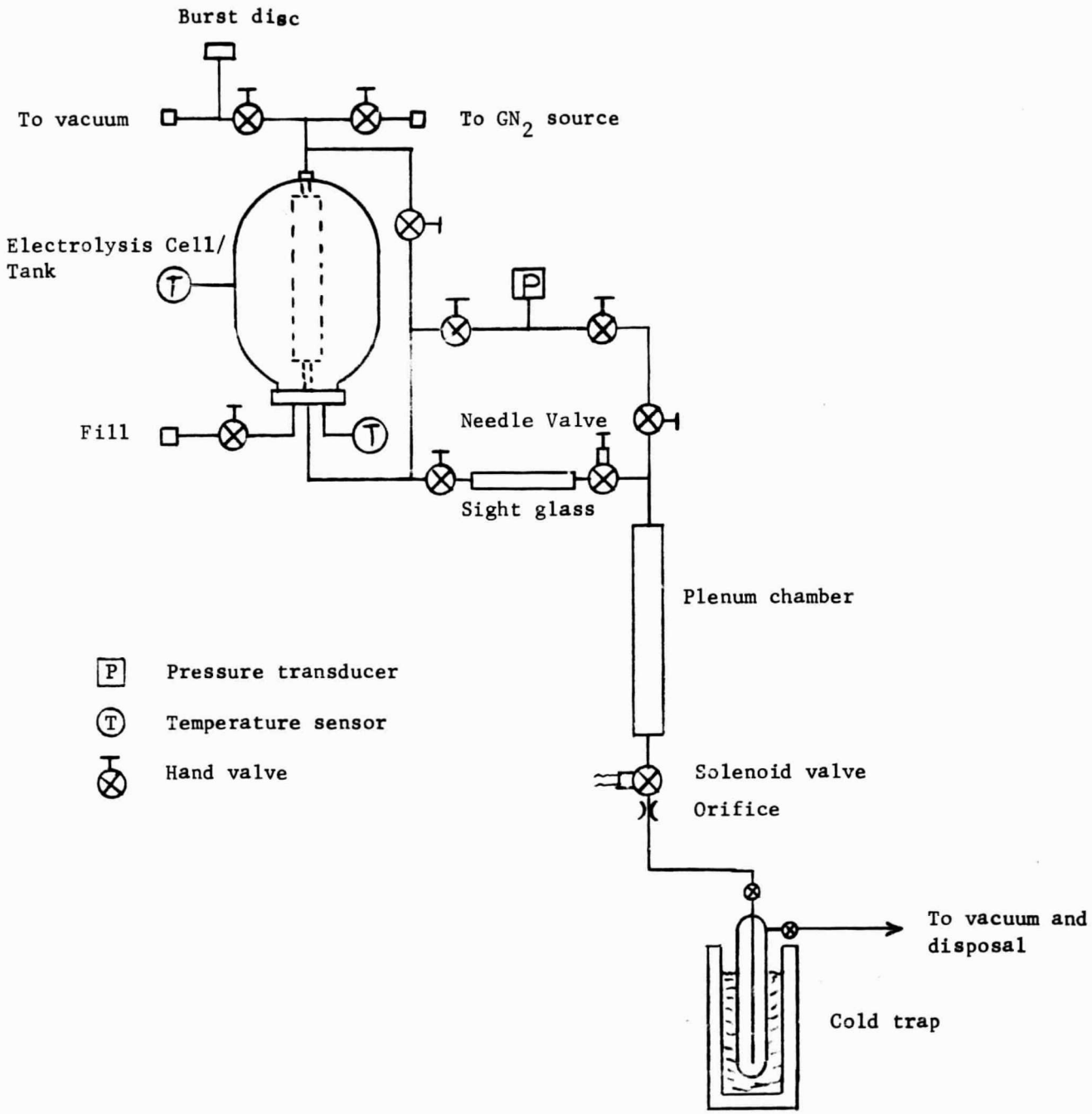
This test was conducted after removing the gas compartment screens. No other changes were made in the electrolysis cell except installation of a new wick. The cell was run overnight to build up pressure and a series of pulses was vented as before. Again fog was observed, liquid was collected in the cold trap, and the current suddenly increased following each pulse. The results of this test indicated that the gas compartment screens were not the primary source of entrained liquid. The source of the large amount liquid in this experiment was more likely the electrode compartment or the external plumbing. Bubbles of generated gas are normally present at the electrode surface and a sudden pressure drop could cause rapid bubble expansion and liquid splatter.

653-18 Purpose:

Test of plenum to reduce sudden pressure changes

The two tests described above served to demonstrate the need to minimize sudden pressure changes within the electrolysis cell during gas venting. This was accomplished by installing a 15 cu. in. plenum chamber in the gas line external to the electrolysis cell with an adjustable orifice (micrometer needle valve) in the line between the electrolysis cell and the plenum chamber. This arrangement is shown in Figure 25. The sight glass was added later to allow visual inspection of the tank effluent gas during expulsion. The needle valve was adjusted so that after pulsing, approximately five minutes was required for the plenum pressure to reach main tank pressure. With this arrangement, the plenum would supply the gas needed for the pulses and would in turn be slowly repressurized by the electrolysis call between pulses. The pressure change in the electrolysis cell with this arrangement is small (i.e., less than 1 psi) and much more gradual than without the plenum. For this and the following tests, the screens were re-installed in the gas compartment.

After electrolyzing for approximately thirty hour to build up pressure in the electrolysis cell, another series of pulses was vented. After each pulse, the current increased slowly and did not reach as high a level as observed previously before the plenum and orifice were installed. Only a very slight fogging was observed in the cold trap but measurements



SCHEMATIC OF TEST STAND

Figure 25

showed that some liquid was still being entrained. Although better than the first series of tests, where more liquid than gas was vented, the liquid in this series was still typically 10 to 50% of the total mass flow. From the vapor pressure of hydrazine (0.5 psia at 100°F) less than 1% of the gas should condense in the cold trap.

Several attempts were made in this series to be sure that the plenum and external lines were dry at the start of each run. At no point in this test sequence was liquid seen in the sight glass. More gas venting tests were schedule to follow the investigation of current decay which will be reported next.

653-24 Purpose:

Investigate Current Decay

In tests 653-16 and 653-17 it had been noticed that current tended to decay with time. For example, in test 653-17 at 2.5 volts, the current was 2.9 amperes after one hour of operation but decreased gradually to 1.6 amperes after 20 hours operation. After being turned off over the week end, the cell resumed operation at 2.0 amperes but dropped off rapidly to 0.4 amperes.

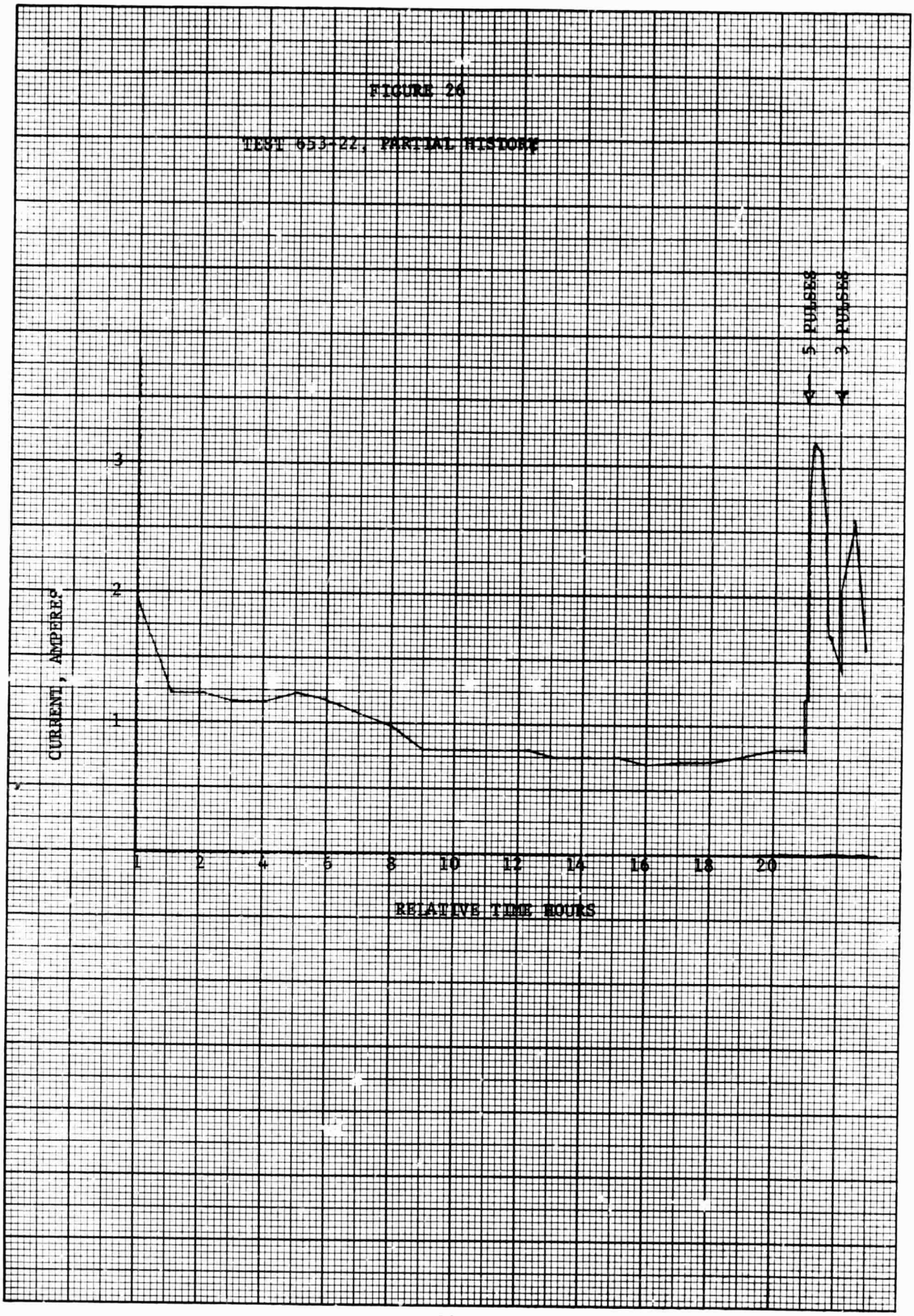
The apparent current decay first was ascribed to some fault in the cell buildup or instrumentation and the main attention was devoted to the gas expulsion tests described above. However, it soon became apparent that considerable current fluctuations were occurring, both decay and sudden increases following gas expulsion. This behavior is illustrated in test 653-22, a portion of which is shown in Figure 26. Relative time starts at the end of the days operation, before which the current data is not very meaningful due to many expulsion pulses.

The graph shows current first decreased rapdily and then more slowly and erratically. Hours 16 to 21 show a slight increase caused by ambient temperature rise after dawn. Then, two groups of 200 millisecond pulses were fired and current increased sharply after each group. The rise was not instantaneous but took place over about a five minute period.

Although later shown to be primarily an effect of differential pressure, it was first thought that this phenomen might be due to some change in the ability of the wick to draw liquid up into the interelectrode space. This could be caused by the porous fibers of the wick being filled with a foreign substance or with solid crystalline electrolyte. It was also suggested that the wick might be squeezed too tightly between the electrodes and hence not be able to perform its function adequately.

FIGURE 26

TEST 653-22, PARTIAL HISTORY



10 X 10 TO ½ INCH 46 1323
KEUFFEL & ESSER CO.

The wick, which had been subjected to eighty-three hours of electrolysis time, was removed from the cell. It was rinsed thoroughly in clean de-ionized water to dissolve any electrolyte which may have accumulated, dried, and re-installed in the cell. Before rinsing the wick, it was allowed to dry and examined under an 80 power microscope. No evidence of contamination or plugging of its porous structure could be seen. When replaced in the cell, the cathode screen was held more loosely around the wick in order to reduce the squeeze on the wick.

The cell was then operated again at 2.5 volts. Initially the current was 1.4 amperes, but decreased to 0.37 amperes after three hours. Gas was vented from the cell in a series of pulses which resulted in the current increasing to 1.1 amperes but then a decrease to 0.41 after one hour without gas venting. The venting and electrolysis cycle was repeated with similar results. This test indicated that neither rinsing of the wick nor reducing the squeeze on the wick improved the performance of the cell.

653-25
653-26
653-27

Purpose:

Investigate effect of liquid level on current decay.

It had been shown in the early tests that earth gravity wicking ability depended on liquid level in the tank. Since it was suspected that some problem in wick functioning existed, two tests were performed at different tank fillings.

The previous test had been conducted with the tank 30% full and an electrolyte concentration of 1.5%. For the next test, neat hydrazine was added to bring the liquid up to 45% full and lower the electrolyte concentration to 1.0%. The cell was then run at 2.5 volts for twenty-three hours, during which time the current decreased from 2.0 amperes to 0.67 amperes. Additional neat hydrazine was added to bring the liquid level up to 90% full and lower the electrolyte concentration to 0.5%. Again a similar decrease in current was observed which tended to indicate that the liquid level in the cell was not the major factor in current decay.

653-28

Purpose:

Test without wick

Since changing liquid level had no significant effect on the above problem, a test was run with the wick removed. Behavior of the cell was nearly the same as when the wick was present. The current held steady at about 1.25 amperes for 1 1/2 hours and then decreased linearly and sharply to 0.2 ampere over a 15 minute period. Opening the shutoff valve and allowing the sight glass to pressurize caused a current surge to 2.5 amperes, followed by a gradual decline.

The interpretation of the above results is that the seat at the top of the electrode compartment had a small leak. O-rings frequently leak in the absence of a differential pressure. After 1 1/2 hours, the leak was sealed, due to slight swelling of the elastomer or other undetermined cause, and the generated gas displaced liquid from the cell, causing current decay. Removing gas from the storage compartment caused liquid to flow back into the cell and restore current.

653-29
653-30

Purpose:

Check cell operation at equalized pressure.

Again with a wick, the unit was operated with 45% and 90% tank filling. Current was constant so long as a bypass valve was open allowing the gas storage compartments to communicate with the main tank ullage. Closing the valve to allow differential pressure to build up caused current decay which was completely restored upon opening. It is concluded that differential pressure opposing or assisting capillary action of a relatively inefficient (in earth gravity) wick is the major factor in the current fluctuations. However, gas bubble accumulation on the anode may also be a factor, as discussed below under the life test.

653-31
653-32
653-33

Purpose:

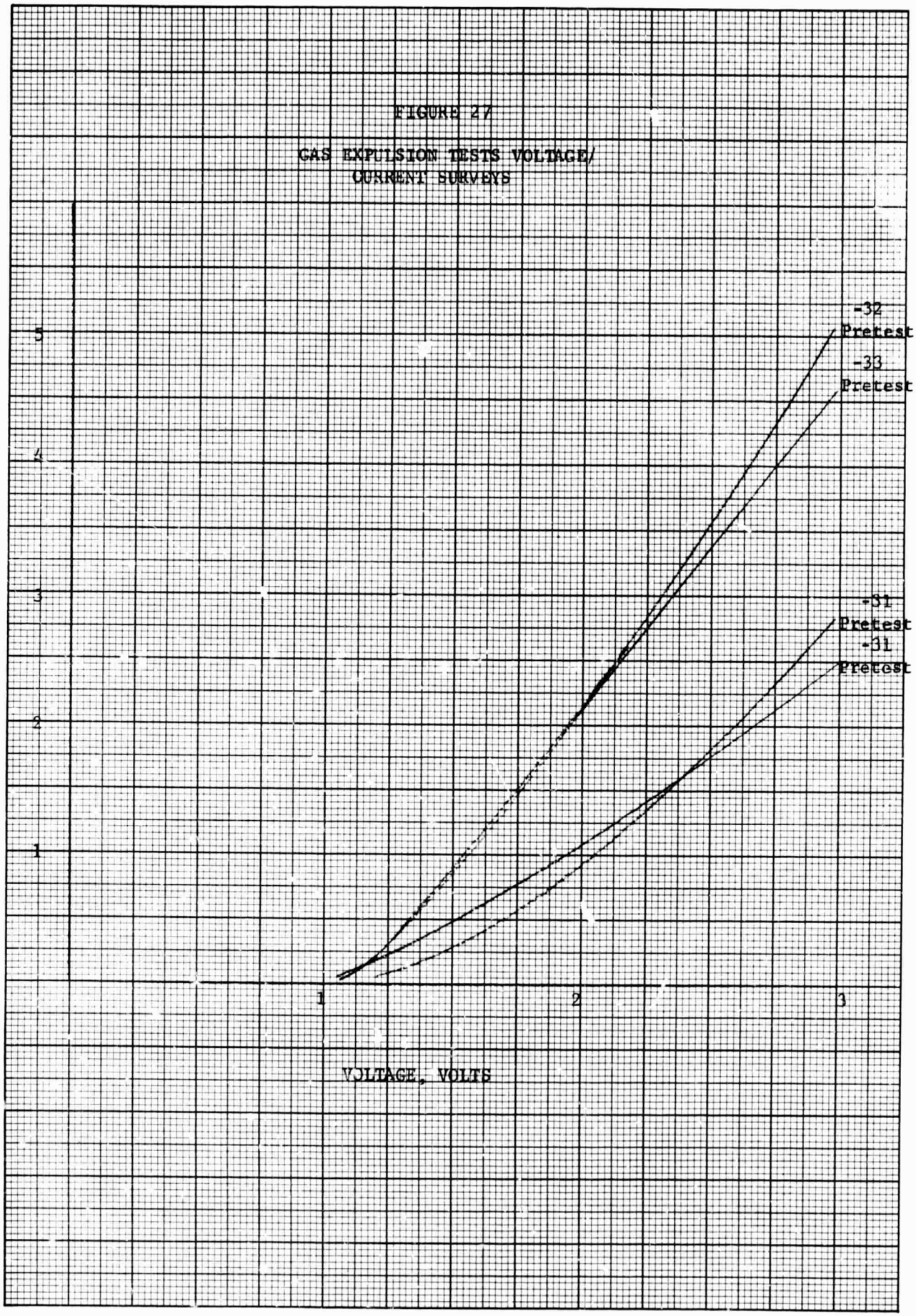
Gas venting in three attitudes

With the tank 30% full, gas was generated and vented in a series of 50 millisecond pulses with the position of the assembly upright, inverted and on one side. The maximum height to which liquid had to be wicked was greatest in the upright position 7.9 inches, least in the side position, less than two inches, and intermediate in the inverted position, 6.0 inches.

The pretest voltage/current surveys shown in Figure 27 reflect the effect of wicking height. Cell resistance is clearly higher for the upright position, 0.59 ohms over the 2 to 3 volt range compared with 0.33 ohms inverted and 0.40 ohms on the side. The lowest resistance for the inverted position may be explained by the wick acting as a type of syphon which causes slightly greater saturation, despite higher wicking distance than in the side position. However, the difference between tests -32 and -33 is no greater than pretest and post test surveys for test -31 and is probably not significant. Cell current during the three tests generally agreed with the survey results.

FIGURE 27

CAS EXPULSION TESTS VOLTAGE/
CURRENT SURVEYS



K&E 10 X 10 TO ½ INCH 46 1323
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

The vented gas was routed through a dry ice or liquid nitrogen cold trap in all tests. The number of pulses and liquid collected as shown in Table II.

TABLE II

Test No.	No. of Pulses) (each pulse 50 msec or about 30 mg gas)	Total liquid in trap, grams	Average weight milligrams/pulse
653-31 (upright)	5	0.921	(mostly water)
	5	0.376	75
	5	0.035	70
	10	0.085	85
	50	1.076	21
	20	0.139	7
653-32 (inverted)	20	0.005	0.25
	20	0.061	31
	50	0.190	3.8
653-33 (side)	50	0.104	2
	34	0.911	(mostly water)
	50	0.316	6.3
653-34 (life test	70	0.064	1
	90	0.018	0.2
	400	9.060	23
	13	.220	18
	12	1.283	(mostly water)
	20	1.475	21

Two problems were experienced. First, the gases were passed into the trap through a length of plastic tubing and out through a water aspirator. On at least three occasions noted, the tubing leaked moist air into the trap and considerable water was condensed from the atmosphere. Secondly, the trend of the data would suggest that a small amount of liquid may have been introduced into the plenum before the start of the tests and came out with the gas pulses.

Unfortunately, the reappearance of significant amounts of liquid later in the life test suggests that accidental liquid in the gas lines is probably not the source. The most likely point of entrainment would be the gas compartment screens.

653-34

Purpose:

Life Test

This test is a longer duration test which will be continued

until the final report is written. The cell will be run at nominal conditions and finally disassembled for inspection.

Only one new effect has been detected. Namely, there may be a decrease of current with operating time, even though pressure is equalized between the internal gas storage volume and the main tank ullage. Decay was slow and tended to be obscured by fluctuations in a temporary power supply used in the early portion of the life test, but was typically a few milliamperes per hour. This effect is thought to result from accumulation of gas bubbles on the anode surface.

Evidence for this conclusion is that venting gas pulses is effective in restoring current but only if there is no small orifice between the cell and plenum. This suggested need for a perceptible abrupt pressure change to dislodge bubbles.

It will be recalled that the present anode design is grooved and has quite broad lands as designed for maximum tolerance to rough handling. However, it should be possible to design an anode which offers a much better escape path for bubbles without compromising structural integrity. It is believed that this approach would solve the problem if, in fact, any real problem exists. This effect had been small during most of the previous testing because pulsing was frequent, as would be the case in normal system operation. It is also possible that more loose contact between the wick and anode would be helpful.

SUMMARY OF PROBLEMS ENCOUNTERED DURING TESTING

Three main problems were encountered, all attributable to differential pressure phenomena:

1. In early gas venting tests, considerable amounts of liquid were entrained in the gas.

2. In these same tests, gas pulsing produced a large but temporary increase in cell current.

3. Over a long operating time, current decayed at a variable rate toward a low final equilibrium value.

In the preliminary design phase it had been realized that it was desirable to avoid differential pressures and their attendant complicated control mechanisms. To a major degree this was successfully accomplished. However, two sources of differential pressure were detected in the breadboard hardware tests.

1. In earth gravity, a hydrostatic head may develop between the liquid level in the gas storage compartment and the level in the main tank. A common situation would be the tank in the upright position, the gas storage area full of gas, and liquid level in the tank above the bottom of the electrolysis cell module. In the case pressure in the gas storage volume would be higher than in the tank ullage volume. This is, of course, true only in a gravity field and would not be a problem in space. The opposite situation might also be encountered if most of the stored gas were used. Liquid would flow into the gas storage volume to replace gas used and the level could be higher than in the main tank ullage. Therefore, the storage volume pressure would be lower than ullage pressure.

SUMMARY OF PROBLEMS ENCOUNTERED DURING TESTING (continued)

The maximum differential pressure created by the described hydrostatic heads is less than 1 psi and might seem at first glance to be inconsequential. However, the liquid surface tension which allows a wick to pull up liquid against gravity is also a small force and may be materially aided or opposed by small differential pressures.

In the tests it was observed that positive differential pressure in the gas storage area (which communicates directly with the wick) caused a partial desaturation of the wick and consequent lower current. A negative differential pressure allowed the wick to become more fully saturated and caused increased current.

2. Gas venting pulses produced a temporary large decrease in pressure in the volume comprised of the top storage compartment, gas outlet tube and free volume around the electrodes. Instantaneously, this could be of the order of 20 psi. Shortly after a pulse, pressure equilibrium is reestablished by liquid flow but, in the meantime, the suddent expansion of gas bubbles on the electrodes causes liquid splattering and droplets were entrained in the vented gas. The sudden large pressure surge also tends to bring in liquid through the wick. This resulted in a large temprorary current increase.

   In early tests, a very large amount of liquid was entrained. Although this was shown to have come primarily from the electrode area, it now appears that the gas compartment screens may contribute a lesser amount. Once again, the fault is probably a differential pressure phenomena which is manifest in the bubble break-through pressure of the screens.

The solution to those problems has been to provide a direct communicating path between the gas storage and ullage volumes by external plumbing connections. This effectively eliminates any liquid movement during changes in system pressure. Also, a small orifice was inserted between the tank assembly and a small external plenum in order to prevent rapid pressure fluctuations in the tank. This measure although effective in the tests, is probably unnecessary if gas in the tank is confined to only one continuous bubble. The latter approach will be taken for the Task VI design, which will also eliminate any external plumbing connections.

In order to avoid all liquid entrainment, it will probably be necessary to eliminate the gas compartment screens. These screens are really not needed for zero gravity performance and had been used primarily to facilitate performance in the one gravity test environment. Further testing is needed relative to gas-liquid separation problems.

CONCLUSIONS RELATIVE TO TASK V

1. Gas generation rate is directly proportional to current. The cell tested performs satisfactorily over the range of voltages, electrolyte concentrations and temperatures likely to be encountered in normal use.

2. Generation of any given quantity of gas requires a fixed number of ampere-hours. However, generation rate will increase with time as the electrolyte becomes more concentrated. For most applications a current regulated power supply would be desirable for more uniform power consumption over the total mission.

3. The glass cloth wick material should be satisfactory in zero gravity operation. The tests show that the wick is not fully saturated in one gravity and consequent dependence of current on tank attitude. However, the wick was never entirely dry and should be uniformly saturated in the absence of gravity.

4. Gas expulsion performance was the same in all tank attitudes. This is taken as evidence that the basic liquid-gas separation method, wherein liquid is returned to the tank, is successful.

5. Proper liquid-gas separation depends on elimination of all differential pressures within the tank assembly during the gas expulsion event. This has been accomplished with the exception of the screen lined gas storage compartments. The screens are normally wet with liquid and bubble break-through pressure must be exceeded before gas may escape. This latter factor is thought to be responsible for the very small amount of liquid which has appeared in all of the gas pulses. The screens may be eliminated without changing the basic separation scheme.

6. The graphite anode was unaffected by electrolysis and is structurally adequate. There is some evidence that gas bubbles may be trapped under the wide lands of the present design. The flutes may be modified to provide easier gas egress without structural compromise.

7. The electrolysis process was completely controllable at all times. However, only normal operation was attempted and further tests under more extreme conditions may be desirable.

8. Relative to Task VI, design information has been obtained which will allow improvements in anode geometry, wicking action, gas-liquid separation and reduction in overall size and weight. Additional test work is recommended to verify the new design.

APPENDIX A

TEST PLAN AND SAFETY PLAN FOR JPL

CONTRACT 951720

TASK V

1.0 Introduction

This document describes the test program to be conducted as part of Task V of JPL Contract 951720 on the HS-209 Hydrazine Electrolysis Cell. The tests described herein are of a developmental nature and included in the test plan are test objectives, system configuration and test facility requirements and safety requirements.

The purpose of this document is to provide information and outline the requirements of the developmental test program on the HS-209 for planning purposes. Detailed test procedures and specific requirements for individual tests will be issued separately as required. All procedures, inspections and tests shall be approved by the cognizant project engineer.

2.0 Reference Documents

The following documents are applicable to the HS-209 developmental test program to the extent indicated herein:

2.1 Government Documents

MIL-P-26536 B	Hydrazine

2.2 HAC Documents

X3106813	Hydrazine Electrolysis Cell, HS-209
DP 30929-002	Processing Parts for Hydrazine Service
DP 30929-004	Specification for Safety or Personnel and Property in the Presence of Hydrazine and Various Passivation Agents.

3.0 General Objectives

The general objectives of the test program as defined in the contract work statement are to:

3.1 Obtain basic information and increase the practical body of knowledge associated with the electrolysis of hydrazine.

3.2 Identification of problem areas.

3.3 Determine techniques required to make the system suitable for spacecraft attitude control.

3.4 Maintain a record log book of all Task V test activities.

4.0 System Configuration

The system to be tested in Task V consists of an electrolysis cell installed in an Surveyor propellant tank. The basic arrangement is shown in HAC Drawing X3106813 and is defined in detail by HAC Drawings X3106834 through X3106854 inclusive.

5.0 Test Description

5.1 Assembly and Checkout

Objective - Preparation of electrolysis cell for test and preliminary verification of functional characteristics.

5.1.1 Dimensional Verification

5.1.1.1 Visual inspection of component parts for imperfection, flaws, damage, etc.

5.1.1.2 Check parts for proper fits and clearances. Verify that parts will fit together as designed.

5.1.1.3 Modify parts as required to achieve proper assembly. Record any changes required in Record Notebook.

5.1.2 Checkout of Gas Vent System.

5.1.2.1 Assemble parts which make up the liquid-gas separation system within the electrode assembly. The parts required are Support Rod, Cap, Dome, Screen Assemblies, Vent Sleeve, Spacers, Insulator, Inner Shell, Bottom Cap retained by a nut and flange. Plug the tube connecting the upper gas compartment to the electrode area.

5.1.2.2 Invert the assembly so that the flange end is upward, support in this position.

5.1.2.3 Fill the screen-lined gas compartments with clean distilled/deionized water. Measure the volume of water put into the assembly.

5.1.2.4 Connect the gas vent fitting in the center of the flange to a regulated source of nitrogen-gas.

5.1.2.5 Slowly admit gas to the gas compartment through the gas vent fitting. As water is displaced, collect and measure the amount.

5.1.2.6 Continue to admit gas until liquid stops flowing, out of the vent holes in the bottom cap.

5.1.2.7 Measure the amount of water displaced from the gas compartment.

5.1.2.8 Disassemble the liquid-gas separation system. Collect and measure any liquid still trapped in the assembly.

5.1.2.9 Compare liquid quantity expelled by gas with the total liquid originally loaded into the assembly to determine the expulsion effectiveness of the liquid-gas separator system.

5.1.3 Cleaning and Passivation

Clean and passivate all parts of the system in accordance with the appreciable sections of HAC Specification DP 30929-002 Processing of Parts for Hydrazine Service. In addition to the electrolysis cell parts and tank, all lines, valves, and fittings to be contact with either hydrazine liquid or vapor are to be passivated.

5.1.4 Tank Safety Tests

5.1.4.1 Proof Test - Conduct a proof test of tank shell at 400 psig.

5.1.4.2 Leak Test - Conduct a leak test of tank with flange attached using nitrogen gas at 200 psig. Flange will contain electrical feed-throughs and other normal fittings.

5.1.5 Assemble Electrolysis Cell

5.1.5.1 Assemble electrode module and sub-assembly and install electrode module in tank.

5.1.5.2 Measure electrical resistance across electrodes.

5.1.5.3 Determine effective tank volume by filling with water.

5.1.5.4 Drain tank and vacuum dry.

5.1.6 Functional Checkout

5.1.6.1 Install the electrolysis cell/tank assembly in the test cell.

5.1.6.2 Verify servicing procedure with hydrazine.

5.1.6.2.1 Propellant loading

5.1.6.2.2 Venting

5.1.6.2.3 Draining

5.1.6.3 Preliminary pressure rise test.

5.1.6.3.1 Load system with hydrazine/electrolyte.

5.1.6.3.2 Survey current versus voltage before and after test.

5.1.6.3.3 Measure and record pressure rise rate for 4 to 6 hours.

5.1.6.3.4 Data required - Voltage current, pressure and temperature, propellant quantity and electrolyte concentration.

5.1.6.3.5 Deservice system.

5.1.6.3.6 Disassemble and inspect electrolysis cell.

5.2 Design Verification Test

Objective - To determine the rate of gas generation as a function of propellant quantity, electrolysis concentration and applied voltage.

5.2.1 Conduct gas generation rate tests by measuring the pressure rise in a known ullage volume with:

5.2.1.1 Initial propellant quantity and electrolyte concentration corresponding to the beginning, middle and end of the mission.

5.2.1.2 Voltage level set at the maximum, mean, and minimum values expected in the mission for each propellant quantity and electrolyte concentration.

5.2.2 The electrodes are to be visually inspected after tests with each propellant quantity and electrolyte concentration. The wick will be thoroughly washed and dried to remove residual electrolyte between tests.

5.2.3 Analyze the test results and compare with predictions based on earlier laboratory experiments.

5.3 Thermal Environmental Test

Objective - To evaluate the effect of ambient temperature on gas generation rate.

5.3.1 Install the electrolysis cell/tank assembly in an insulated enclosure.

5.3.2 After conditioning the cell/tank to $45^{\circ} \pm 5^{\circ}F$, apply voltage to the electrolysis cell and determine gas generation rate by measuring pressure rise in the tank.

5.3.3 Repeat with cell/tank conditioned to $120^{\circ} \pm 5^{\circ}F$.

5.3.4 Analyze test results.

5.3.4 Disassemble cell and inspect the electrodes.

5.4 Gas Expulsion Test

Objective - To demonstrate liquid-free gas expulsion with tank in any of three attitudes.

5.4.1 Assemble electrolysis cell/tank. A weight is to be fastened to the end of each of the long "tails" on the wick for this test to insure that the wick will be partially submerged in liquid in any attitude.

5.4.2 Fill tank with hydrazine/electrolyte mixture to about 30% of its full capacity.

5.4.3 With tank in upright position (flange downward), apply voltage and measure pressure rise rate.

5.4.4 Vent a known quantity of the generated gas through a cold trap to freeze out any liquid. Measure the quantity of liquid trapped.

5.4.5 Repeat steps C and D above with tank inverted (flange upward) and with tank on its side.

5.4.6 Analyze the results to determine if any liquid in excess of the normal saturated vapor was expelled with the gas in any tank position. Also determine if tank attitude has any effect on gas generation rate.

5.5 Extended Life Test

Objective - To determine if any adverse conditions result from extended operation of the electrolysis cell.

5.5.1 Carefully examine all parts of the electrolysis cell and note their condition in the record log book. Take photos as may be appropriate. Weigh the anode and cathode.

5.5.2 Assemble the electrolysis cell/tank. Load to 90% capacity with hydrazine/electrolyte.

5.5.3 Apply voltage to the electrolysis cell and monitor voltage, current, pressure, and temperature. Record these parameters periodically. When tank pressure reaches 200 psig, vent the gas to reduce tank pressure to approximately 50 psig.

5.5.4 Continue life test for approximately two months. At the end of that time de-service the system and do the following:

5.5.4.1 Collect a sample of hydrazine/electrolyte for analysis.

5.5.4.2 Collect samples of any particulate contaminant present for analysis.

5.5.4.3 Disassemble the electrolysis cell and visually inspect all parts. Note any changes which may have occurred.

5.5.4.4 Weigh the electrodes and compare with pre-test weights.

6.0 Facilities Requirements

6.1 Safety

6.1.1 Hydrazine - Hydrazine in a very toxic and combustible material and must be handled with extreme caution and strictly in accordance to accepted procedures. HAC Document DP 30929-004 "Specification for Safety of Personnel and Property in the Presence of Hydrazine and Various Passivation Agents" shall apply to this program.

6.1.2 Gases - One of the products of hydrazine electrolysis is hydrogen gas which is highly combustible when mixed with air or is in the presence of other oxidizers. The requirements for test cell ventilation and absence of sources of combustion included in the above document (DP 30929-004) relative to hydrazine shall be equally applicable to hydrogen gas. These requirements shall apply whenever there is the possibility of hydrogen leakage from the system and whenever hydrogen is being vented.

6.1.3 Pressure Vessels - The Surveyor propellant tanks shell (HAC P/N 254094 or P/N 254175) to be used in this program has design burst pressure of 1050 psi. With a safety factor of 4:1, the maximum man-rated operating pressure is 262.5 psi. The individual tank to be used for the hydrazine electrolysis cell shall be proof-tested at 400 psi and subsequently inspected for damage before use. When ever a tank is being pressurized it shall be located behind a suitable barracade. Under no circumstances shall any personnel be on the tank side of the barracade if the tank pressure should exceed 262.5 psi. Normal maximum operating pressure for this test program is 200 psig and under no circumstances shall it be allowed to exceed 262.5 psi except for proof-testing.

Should the tank be subjected to any shock, blow, be dropped or otherwise mis-handled, it shall be again proof-tested at 400 psi before it is used again for test purposes.

6.2 Instrumentation and Test Equipment - The following equipment is required for performance of the tests described herein:

Power Supply - Regulated D.C. NJE Model EQR-10-10

Pressure Transducer 0-200 psi

Thermocouples - 0-120°F, Chromel-Alumel

Recorder - Periodically sample data on voltage, current, pressure and temperature.

Solenoid Valves (3)

Hand Valves (5)

Lines, Fittings, Etc.

6.3 General Facility Requirements - General Facility requirements include the following:

Hydrazine

Solvents

Nitrogen

Helium

Propellant loading and disposal facilities

Cleaning and passivating fluids and facilities

Safety Equipment

Recorder Paper

Other equipment, facilities, supplies normally required for hydrazine propulsion system testing.

AMENDMENT TO TEST PLAN

Add Paragraph 5.6 as follows:

5.6 Additional Investigations

Objective - To eliminate the current fluctuations and liquid entrainment in vented gas which have been observed during the development testing of the electrolysis cell.

5.6.1 Gas Venting Tests

5.6.1.1 Install a plenum chamber and small adjustable orifice between the electrolysis cell gas outlet port and the simulated gas thruster to reduce sudden pressure changes within the electrolysis cell when gas is vented.

5.6.1.2 Conduct gas venting tests with plenum and orifice installed, while the electrolysis cell is in each of the three positions described in Paragraph 5.4, to determine the effect on quantity of liquid entrained in the vented gas and the effect on cell operating parameters.

5.6.2 Wick Tests

5.6.2.1 With wicks installed in normal manner in the electrolysis cell, determine the electrolysis rate and observe variations with time at various electrolyte concentrations and liquid levels in the cell.

5.6.2.2 Reduce the confining pressure on the wick and check cell performance under one or more of the conditions of Paragraph 5.6.2.1.

5.6.2.3 Remove wick from electrolysis cell. The electrode spacing is to be maintained at near the same distance as inprevious tests with the wick by suitable insulating spacer material. Conduct electrolysis performance tests at the same conditions as for Paragraph 5.6.2.1. Compare the results.

5.6.3 Other Tests - Conduct other tests which may be needed to verify proper cell operation. Any such tests will not increase cost or scope of this program and will be coordinated with JPL before start.