

In a plasma test with the modified light baffle the following results were obtained. The input current density corresponded approximately 6×10^{-7} amp/cm² ion current. The net ion flux was reduced 1000 times. The electron attenuation was a reduction from an electron current of 1×10^{-7} amp/cm² to $\frac{1}{30}$ of that value. This test determined the amount of attenuation that could be expected for the ion trap. However, the high-energy tail of the ion distribution and the high electron energy do introduce some uncertainty, but the test provides more information than the electrolytic plots as to the attenuation for marginal potentials.

The influence of the plasma on high-voltage breakdown was evidence in a test on the Harvard College Observatory OSO experiment. During this test, a plasma exposure at an elevated pressure of 10^{-3} torr and an ion flux of 5×10^{11} ions/cm²-sec, which corresponds to an orbital ion density of approximately 10^6 particles/cm³, produced arcing in the high-voltage system. These arcing conditions were not duplicated in a plasma-free environment until a pressure of 10^{-2} torr was reached. This would seem to indicate that the presence of the plasma produces an effective pressure that is higher than the actual pressure. It would not be unreasonable to assume that this effect is operative at lower pressures, in which case a plasma environment could induce breakdown when the pressure was "too low" to sustain it.

When a positive electrode is exposed in a plasma, it assumes the plasma potential and drives the other electrode negative with respect to the plasma. The amount of this potential shift is dependent on electrode voltages, areas, and the plasma parameters. The mechanism for this shift is the collection of plasma electrons by the positive surface. The collected electrons drive the other exposed surfaces negative until ions and electrons are collected in ratios that establish an equilibrium potential.

OGO-VI experienced such a potential shift. The potential of the spacecraft ground was driven about 26 v below the plasma potential. As a result, several experiments to measure plasma parameters did not have sufficient sweep voltages to determine the plasma parameters fully. The exposed positive potential is thought to have resulted from a short of the positive solar cell potential to the frame of the solar paddles. Exposed busses have produced similar potential shifts in other spacecraft. These potential shifts can also increase the energies of the ions or electrons that strike the spacecraft.

A test on a model of the OGO-VI power system in the simulated ionospheric plasma demonstrated that the potential shift could result from a shorted solar cell module, and displayed the proper functional behavior to duplicate the orbital observations.

Summary

This test environment has been extremely useful in demonstrating plasma-hardware interactions. These interactions can explain some malfunctions and failures observed in orbiting spacecraft. In light of these observations, tests should be made of high-voltage systems in a charged-particle environment so that their plasma susceptibility can be determined and, if necessary, corrected. The effectiveness of ion traps should be evaluated with consideration to higher-than-expected ion energies. The variable ion energy that can be obtained with this environment leads itself to the ion trap evaluation.

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Prototype Electrolyzer for Oxygen Generation from Water Vapor

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Introduction

A WATER-VAPOR electrolysis cell¹⁻⁴ operates by passing a humid air stream continuously through one of the two compartments in the cell. Water vapor is then absorbed by the immobilized electrolyte H₂SO₄ in a silica gel matrix sandwiched between two platinum screen electrodes. A d.c. voltage sufficient for water electrolysis is imposed across the electrodes. The absorbed water is subsequently electrolyzed, generating oxygen at the anode and hydrogen at the cathode. The O₂ enters the air stream and the H₂ is collected. The H₂ and O₂ gases are prevented from mixing by a membrane that separates the two compartments. A recent theoretical study has shown that the water-vapor electrolysis unit should operate without impaired performance at reduced gravity.⁵ This Note deals with a 104-day test of a $\frac{1}{4}$ man capacity ($\frac{1}{2}$ lb O₂/day) prototype unit for a space mission use.

Most experimental work with water-vapor electrolysis units has dealt with steady-state operation at a fixed set of experimental conditions. However, in a spacecraft cabin the unit probably would utilize the perspired and expired water vapor of the occupants and, therefore, would experience a range of both inlet humidities and temperatures. Therefore, the primary objective of this effort was to demonstrate the ability of the aforementioned unit to function reliably for a long time under varying atmospheric conditions of temperature and relative humidity within the acceptable range for human occupancy. A secondary objective was an

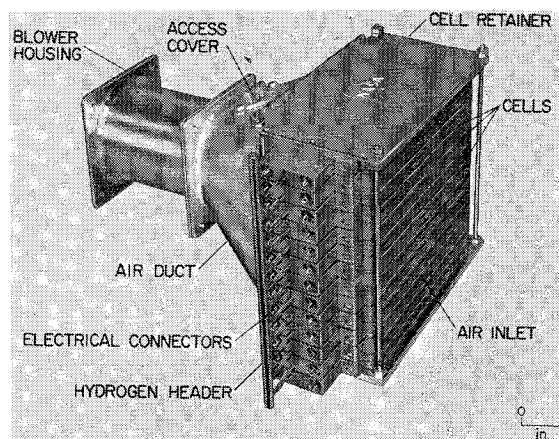


Fig. 1 One-quarter-man capacity water vapor electrolysis unit.

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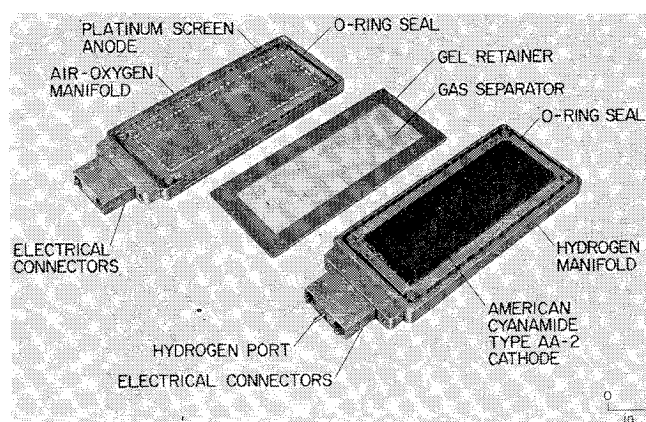


Fig. 2 Single cell components.

investigation of trace contaminants coming from the electrolysis unit under controlled air conditions to determine the effluent gas purity.

Apparatus and Procedure

The basic design features of the $\frac{1}{4}$ -man capacity water-vapor electrolysis unit (Fig. 1), using a sulfuric acid-silica gel matrix, have been described elsewhere.^{4,6} The assembled unit shown in Fig. 1 includes twelve single cells, a cell retainer, an air duct and blower, and a hydrogen header or collector. The cell retainer, air duct, and blower housing are made of 24-gage light-weight aluminum. A variable speed, 28 v, d.c., vaneaxial blower was used to draw air through the cell. The total weight of this system is 10 lb.

Figure 2 is a disassembled single cell. The active electrode area for the anode and the cathode was 0.0765 ft². For extended evaluation the $\frac{1}{4}$ -man unit was wired to provide for three groups of four cells connected in series electrically. Each of the groups of cells consisted of four cells connected in parallel electrically.

During the operation of the $\frac{1}{4}$ -man unit in the ambient air atmosphere, gas samples were collected periodically from the effluent air stream and the hydrogen header. These samples were analyzed by mass spectrometry for trace contaminants, specifically volatile organic compounds and sulfur-containing compounds.

After the 2500-hr test at the Ames Research Center the unit was sealed in an air-tight container and shipped to Battelle Memorial Institute, Columbus, Ohio, for a more detailed evaluation of trace contaminant production (see Ref. 2 for method used).

The effluent gas was analyzed specifically for sulfuric acid, arising from aerosol formation at the anode, and for ozone. A special glass fiber sheet filter (Mine Safety Appliances 1106B) that retains over 99.9% of the acid droplets 0.3 μ in diameter or larger was used to trap the aerosol for analysis by titration. Ozone was analyzed for continuously, using a MAST Analyzer (Model 724-2) and a strip chart recorder.

Theoretical equations have been derived that relate cell operating parameters, i.e., temperature, humidity, voltage,

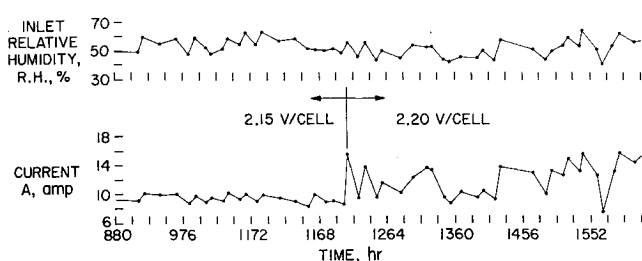


Fig. 3 Representative data from 2500-hr test.

Table 1 Operating conditions

| | Nominal | Actual average | |
|--|---------|----------------|------|
| Cell voltage | 2.20 | 2.15 | 2.20 |
| Current density, amp/ft ² | 44.7 | 29.4 | 39.2 |
| Inlet relative humidity, % | 44.0 | 55 | 50 |
| Inlet temperature, °F | 74.6 | 73 | 72 |
| Airflow rate, std ft ³ /min | 16 | 16 | 16 |
| Time in operation, hr | ... | 792 | 1344 |

current density, and airflow rate, to the steady-state electrolyte concentration.¹ Using the derived equations and vapor pressure versus temperature data reported for sulfuric acid,³ the steady-state electrolyte concentration (for operation of this unit) was calculated to be 58 wt % sulfuric acid for the nominal operating conditions shown in Table 1. Therefore, 58 wt % sulfuric acid was used for impregnating the matrix. Cell voltage and current density were selected from a test cell polarization curve.⁴

It should be emphasized that if the humidity to which the vapor cell will be subjected is known before cell assembly, then the cell can be impregnated with the proper acid concentration to prevent flooding or drying within that range. A higher humidity range requires a less concentrated acid. For example, using a small test cell and 48 wt % H₂SO₄ the cell operated satisfactorily from 54% to 78% relative humidity at 77°F.

Test Results and Discussion

Figure 3 shows representative data obtained on the $\frac{1}{4}$ -man prototype unit during the 2500 hr of operation on laboratory air. These curves show that the unit current varies with changes in the inlet relative humidity at essentially constant inlet air temperatures ($72.8 \pm 1.0^\circ\text{F}$), airflow rate, and unit voltage. It can also be seen from the curves shown in Fig. 3 that when the cell voltage is increased from 2.15 to 2.20 v/cell the change in current which is directly proportional to the oxygen generation rate is greater for the same fluctuation in relative humidity. This result can be explained on the basis of the polarization curve,⁴ which clearly shows that at higher overvoltages, small changes in the overvoltage give rise to large changes in the current density.

The gas samples, which were collected periodically from the unit during the extended test and analyzed on the mass spectrometer, showed no evidence of trace contaminants. However, the lower detection limit of the mass spectrometer was only 5 ppm.

After the unit was installed and operating at Battelle Memorial Institute, gas samples were taken and analyzed with a mass spectrometer having a lower detection limit of 0.01 ppm by volume (see Table 2). All identified compounds are present in quantities below the 90-day continuous exposure limit for spacecraft.⁷

A more detailed analysis for sulfuric acid aerosol and ozone was also performed at Battelle.² The analytical results are shown in Table IV of Ref. 2, which also shows the 90-day continuous exposure limit for comparison. Since there are no data available on sulfuric acid as far as the continuous ex-

Table 2 Analysis of gases^a produced from sulfuric acid, water-vapor electrolysis cell

| Sample | Mole percent | | | Parts per million | | |
|----------|----------------|----------------|----------------|-------------------|---------------------------------|-------------------------------|
| | O ₂ | N ₂ | H ₂ | CO ₂ | C ₃ -HC ^b | C ₂ H ₆ |
| Oxygen | 17.6 | 82.1 | 0.26 | 6 | 0.01 | <0.01 |
| | 17.2 | 82.7 | 0.07 | 6 | <0.01 | <0.01 |
| Hydrogen | 0.05 | 0.19 | 99.8 | 0.9 | 0.05 | 0.4 |
| | 0.04 | 0.18 | 99.8 | 1 | 0.03 | 0.3 |

^a Limit of detection = 0.01 ppm; HCl, C₂H₄, SO₂, H₂S, and COS were <0.01 ppm each in both O₂ and H₂ samples.

^b Unidentified C₃ hydrocarbon.

Table 3 Analysis for ozone and sulfuric acid^a

| Contaminant | Voltage, v | Found, ^b ppm | 90-day limit, ^c ppm |
|---------------|---------------|----------------------------|-----------------------------------|
| Ozone | 2.15 | 0.02-0.05 | 0.02 |
| | 2.20 | 1 | |
| Sulfuric acid | 2.15 | 0.22 | 0.1 ^d |
| | 2.20 | 0.28 | |

^a Inlet air temperature $75 \pm 5^\circ\text{F}$ and inlet relative humidity $50 \pm 2\%$.

^b Parts per million by volume based on the O_2 plus N_2 mixture at a ratio of 1:4 and at 1 atm pressure and 25°C .

^c ppm by volume of gas at 1 atm and 25°C (Space Science Board, 1968).

^d See text.

posure limit is concerned, a value of 0.1 ppm by volume will be assumed.⁸ Although the concentrations of acid and ozone are higher than the acceptable limits for these materials, a standard glass filter (Flanders Filter Inc., Riverhead, N.Y., 6C-33G size A) was able to reduce the acid spray to a level less than 2×10^{-6} ppm, which is acceptable. Also, a standard charcoal filter (Barneby Cheney Model PAB Type Filter, Type AC charcoal, 6-10 Tyler mesh size) reduced the ozone concentration to an undetectable level (<0.0025 ppm). The lower limit of detection for ozone is also acceptable for continuous exposure for 90 days.

Visual inspection of the electrodes after disassembling the unit upon completion of the 3268 hr of total test time failed to reveal a significant loss of platinum black from the cathode. Discoloration of the gel matrix, however, indicated some loss of platinum black apparently from the cathode. (Since the platinum catalyst used on the anode was not flaky, platinum black, but instead an adherent platinum catalyst, it is doubtful the discoloration was due to platinum from the anode.) The appearance of the anode was unchanged.

After over 3268 hr of operation this unit gave no indication of physical or operational degradation. Cell resistances measured with a General Radio Impedance Bridge at 1000 cps before start-up and at the end of the 2500-hr test showed little change. The average resistance for each cell was $0.102 \pm 0.008 \Omega$ initially and $0.100 \pm 0.005 \Omega$ after testing.

The unit used in this extended evaluation was designed to operate nominally as a $\frac{1}{4}$ -man capacity unit ($\frac{1}{2}$ lb O_2 /day). In practice the unit operated at an O_2 production rate as high as 0.756 lb/day and as low as 0.142 lb/day (at 2.2 v) depending on the inlet relative humidity. The 0.756-lb/day rate was achieved at 60% relative humidity and 76°F and the 0.142 lb/day rate at 30% relative humidity and 72°F .

Conclusion

Reliable operation of a $\frac{1}{4}$ -man capacity water-vapor electrolysis unit for an extended period of time has been demonstrated. The range of relative humidity and temperature that the unit could tolerate without impaired performance was much greater than the nominal ranges anticipated in manned closed environments. The range of inlet relative humidities over which the prototype unit was operated without drying out or flooding was 30% to 70% at an average temperature of $72.8^\circ \pm 1^\circ\text{F}$.

Gas analysis for trace contaminants indicated the presence of H_2SO_4 aerosol and ozone. Although the ozone and acid aerosol concentrations were higher than permitted for continuous human exposure, standard filters reduced the concentrations well below the toxic level.

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Minimizing Launch Cost by Institutionalization of Launch Facilities

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THE national space program has required a very significant investment in launch facilities and equipment. It may require an additional investment to support: a) the development of space transportation systems; b) the establishment of permanent manned space stations/bases; c) the advent of nuclear propulsion systems; d) expanded lunar exploration; and e) planetary exploration. The operational costs at the launch site constitute a significant portion of the cost picture, particularly for extended programs. Institutionalization of our launch facilities and support equipment would lead to more economical multiprogram support of a variety of space vehicles, compared to further extension of the current program-oriented, dedicated launch facilities.

Development of support equipment for the most part starts at a later date than that of the flight article, as indicated in Fig. 1. Special support equipment requirements usually cannot be defined until flight hardware concepts have been formulated and preliminary design specifications have been prepared; therefore, less time is available in which to develop such equipment, even though its development will determine the efficiency of the operational process. Still, it must be ready for operation at the same time as the flight hardware. Therefore, from an over-all management standpoint, it is advantageous to utilize to the maximum extent possible institutional facilities for supporting services and apply resources only for the development of special support equipment. This management approach will reduce program risks by introducing the minimum number of developmental items into a new program.

Prior to entering into a major effort to institutionalize launch facilities, the following requirements need to be established: a) a multiprogram environment, b) a high degree of program independence in the launch site configuration, and c) a high degree of program independence of the launch site management structure.

Ground support and launch operations for major space vehicles require support of the following types: power, environmental control, propellant loading, communications,

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