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INTRODUCTION

This report summarizes the first six-month effort devoted to Grant NGR 01-002-035. The period included is July 1, 1967, through December 31, 1967*

BROAD OBJECTIVES OF GRANT RESEARCH

A) Applying basic chemical engineering viewpoints and approaches to electrochemical systems (e.g., fuel cell systems) one at once recognizes that any such system inherently comprises a complexity of chemical and physical phenomena, such as the following:

Transport phenomena
(e.g., mass, heat, momentum, charged particle transfer)

Sorption phenomena
(e.g., adsorption and desorption)

Chemical and electrochemical kinetic phenomena

Thermodynamics

Miscellaneous areas of physical chemistry
(e.g., non-ideal solution phenomena)

Hence, a major objective of the present grant research is to obtain and develop improved integrated understanding of the basic physical and chemical phenomena involved in advanced electrochemical systems, with initial emphasis on fuel cell systems of interest to NASA.

B) A second major objective is to consider, conceive, analyze, and develop new fuel cell system concepts.

* * * *

The above objectives are to be accomplished with the aid of the most up-to-date available analytical and experimental tools and methods. A supplementary objective is to promote academic interest and to provide advanced training in applied electrochemistry

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*Also included are the program plans for the remainder of the present grant period and also for a proposed extension of the grant. A formal proposal for the latter is to be submitted separately.

and to encourage commercial applications of data and technology developed during the course of the Grant efforts.

PROGRESS TO DATE

Objective A:

1) We are proceeding with the analysis of an advanced fuel cell of the gas diffusion type of current interest to NASA, namely an Allis-Chalmers porous matrix fuel cell. Starting with the macroscopic model schematically represented in Figures 1 to 3 and discussed in Appendix A, we are presently concentrating on developing an improved (i.e., more accurate and complete) mathematical representation of the predominent, performance-controlling phenomena occuring within the active pores of the electrodes of this type and related type fuel cells. Appendix A summarizes the progress made to date on this effort.

2) Fabrication and installation of experimental facilities for the advanced basic study of fuel cell and related electrochemical systems are well under way and nearing completion. Emphasis is being placed upon providing ample instrumentation for the precise control and measurement of the physical variables to be studied. An attempt has been made here to provide instrumentation and related experimental facilities capable of fulfilling all reasonable foreseeable future needs with regard to precision requirements and versatility. These experimental facilities comprise two categories:

a) Basic precision equipment and instrumentation for the controlled operation of fuel cell systems and for making conventional performance measurements, such as of total cell e.m.f.'s, half-cell e.m.f.'s, and ohmic polarizations as functions of current density, temperature, pressure, and electrolyte composition.

b) Instrumentation for obtaining quantitative data on individual "polarization" phenomena (e.g., sorption and kinetic) and their influences upon the capacities and other performance characteristics of fuel cell and related electrochemical systems, using galvanostatic, potentiostatic, and potentiodynamic methods.

Summarized details of the experimental facilities are given in Appendix B. Most of the major basic items of electrical and electronic equipment have been or are being purchased from funds previously made available to the Research Institute from a State of Alabama bond issue. Some items were already on hand.

Objective B:

Preliminary consideration has been given to new relatively unique, advanced fuel cell system concepts. Appendix C describes in some detail a new flow-through system concept in which continuous circulation of an emulsified electrolyte is employed in an effort to circumvent the present limitation of flow-through systems owing to the low solubilities of hydrogen and oxygen in strong aqueous electrolytes at ordinary temperatures and moderate pressures.

IMMEDIATE AND FUTURE PLANS

Funds provided by the present grant have been essentially exhausted, and a formal request for continuance of the grant is being submitted separately which would provide funds for an additional 10 man-months of professional effort, this effort to be directed to the following research tasks:

1) Completion of the programing and testing of the advanced mathematical representation of the predominant physical and chemical phenomena occuring within the electrodes of gas diffusion type fuel cells referred to in Appendix A. This is presently being done with the aid of the Univac 1107 computer at the Research Institute. The possible use of analog and/or hybrid techniques for the solution of the present and/or more complex mathematical models will be considered later.

2) Completion of installation of the basic experimental facility described in Appendix B. This should take about another month.

3) Upon completion of installation of the basic experimental facility, it will be briefly employed to follow the performance of a standard two-cell Allis-Chalmers fuel cell module, operated under a variety of electrical load and temperature conditions. This will be done for the purposes of a) gaining familiarity with this facility and b) gaining familiarity with the gross operating characteristics of a "typical" advanced gas diffusion type fuel cell system.

4) Following these experiments, one of the above two-cell modules will be modified into a single cell unit, upon which conventional as well as special studies will be performed for the purposes of a) gaining additional insight into the intrinsic performance characteristics of a single cell not subject to the influence of cells connected in parallel or series with it,

b) obtaining precise overall e.m.f., half-cell e.m.f., and ohmic polarization data against which performance predictions obtained by means of the mathematical model discussed in Appendix A may be compared, c) exploring heretofore at best inadequately explainable causes of "inevitable" deterioration of multicell systems with time (for example, the precise effects of accumulation of "trace" impurities in the reactants, hydrogen and oxygen upon the duration of efficient performance of fuel cells), and d) further exploring potential benefits of substituting cesium (or rubidium) hydroxide for potassium hydroxide presently employed as electrolyte.

5) Concurrently with the above, preliminary engineering analyses of new fuel cell system concepts will continue. Laboratory-scale equipment for demonstration and preliminary testing of the concept described in Appendix C is presently being designed. This will be continued and the necessary equipment and supplies purchased, with the objective of expeditious assembly of the equipment and preliminary testing of the concept.

6) Further attention is planned toward developing a scheme for carrying out meaningful quantitative or semi-quantitative analyses of <u>overall</u> fuel cell systems in terms of the various transport, kinetic, and sorption phenomena involved, expressed as "polarizations", by means of which those individual phenomena or process steps most likely to limit the capacity and performance of an overall system can be rapidly identified and logical priorities given to subsequent research and engineering efforts. A tentative approach to developing such a scheme has been outlined in Appendix A or U. of A. Research Institute Unsolicited Research Proposal entitled: ANALYTICAL AND EXPERIMENTAL STUDY OF FUNDAMENTALS OF FUEL CELL SYSTEMS AND ELECTROLYSIS CELL SYSTEMS (12/66).

This above approach was originally directed to static gas diffusion electrode systems, but with reasonable modification should be equally adaptable to other electrochemical system concepts, such as advanced flow-through electrode systems. Therefore, consistent with NASA's expressed interest in increased grant efforts being directed toward new, advanced system concepts and to their underlying principles (which <u>basic</u> principles should remain unchanged), emphasis of future analytical efforts, such as proposed here, will be so directed.

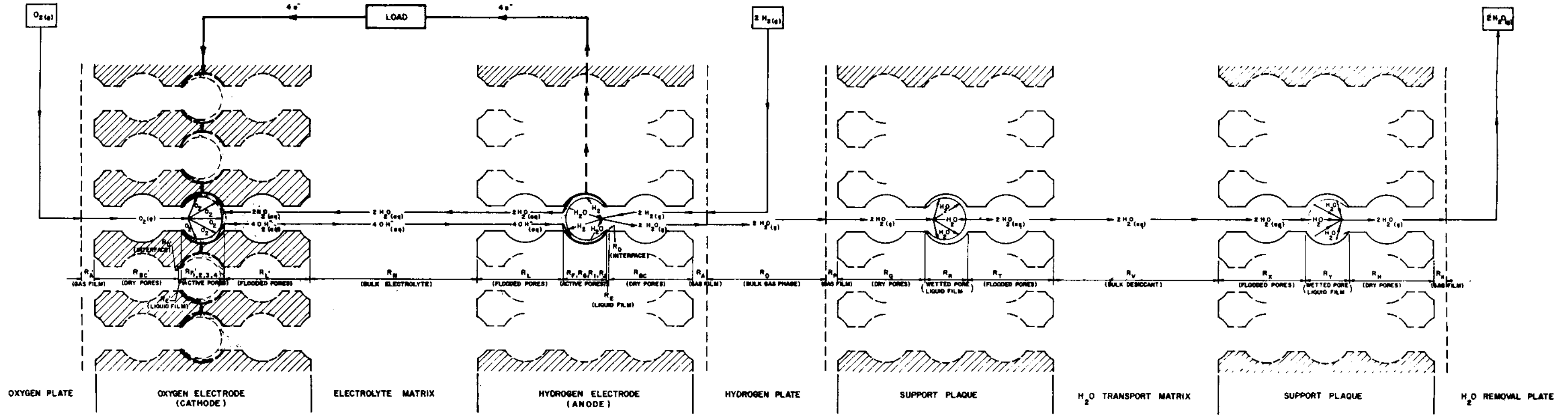

FIGURE 1. IDEALIZED PICTORIAL REPRESENTATION OF A CROSS SECTION TAKEN THROUGH A SINGLE ALLIS-CHALMERS FUEL CELL

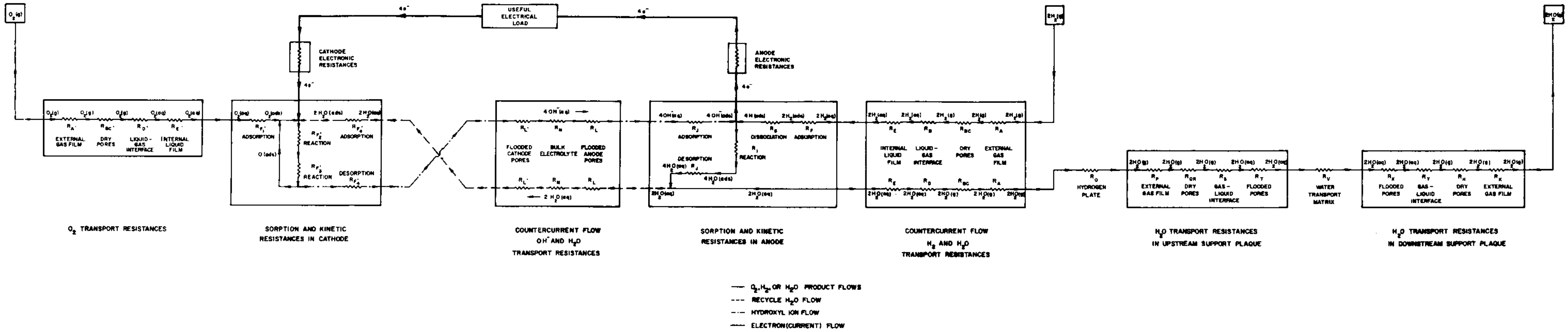

FIGURE 2. SCHEMATIC REPRESENTATION OF TRANSPORT, SORPTION, AND KINETIC RESISTANCES IN AN ALLIS-CHALMERS FUEL CELL

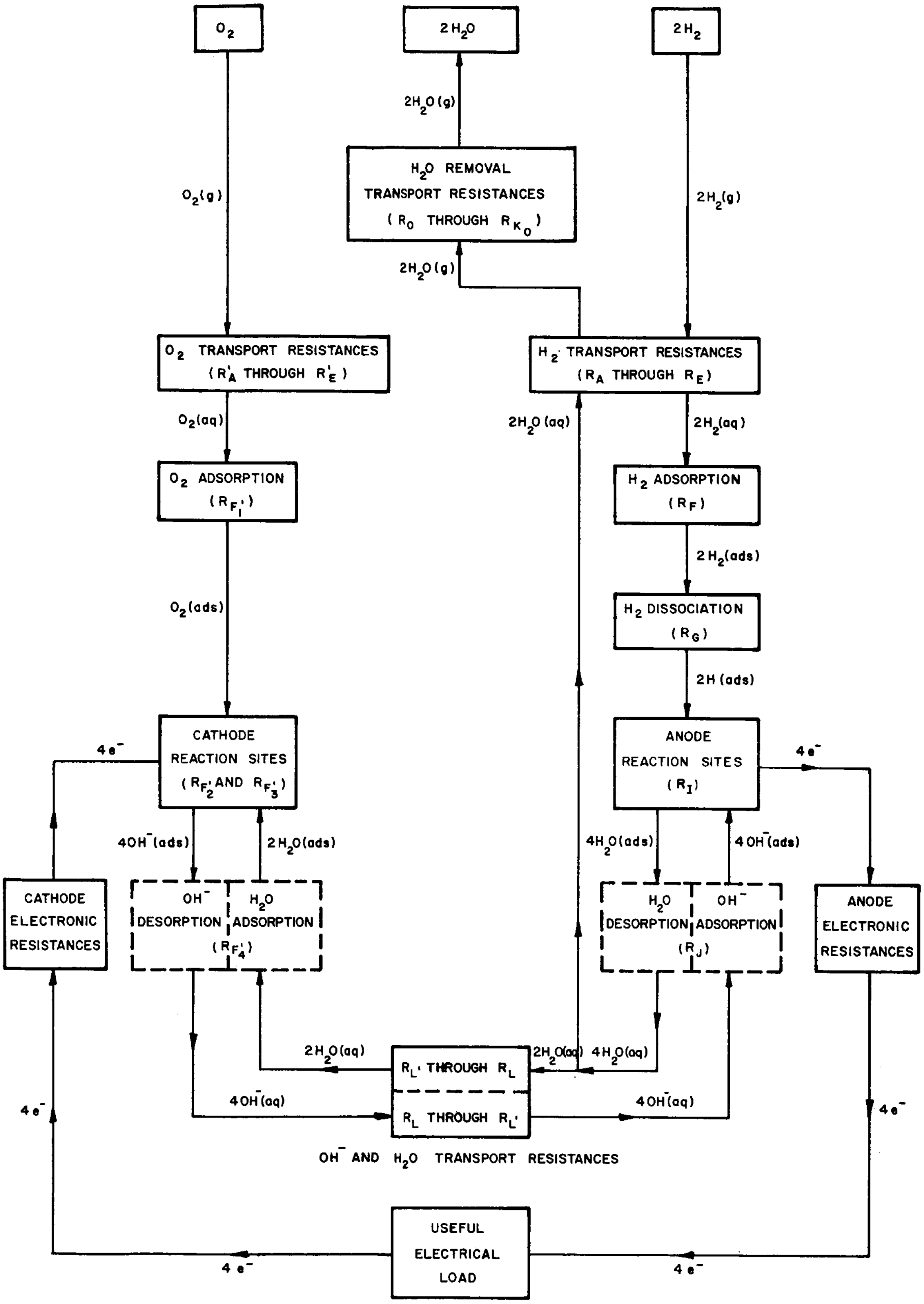

FIGURE 3. BLOCK DIAGRAM OF TRANSPORT, SORPTION, AND KINETIC RESISTANCES IN AN ALLIS-CHALMERS FUEL CELL

APPENDIX A

Analysis of Porous Electrodes Considering Contributions from Both Exposed and Submerged Reaction Zones

A conventional porous electrode gas diffusion fuel cell basically consists of an anode, electrolyte, and cathode in series plus a gas plenum (or "cavity") for each of the reactants immediately adjacent to the dry sides of the electrodes. Confining our discussions to the use of liquid electrolytes, the above design allows for the simultaneous existence of a) flooded, b) wetted but not flooded, and c) dry zones within the electrodes. Granting that the dry zones within an electrode may possibly contribute to ionization of a reactant gas, the basic electrochemical reaction or reactions involved take place only at the active catalytic sites on solid surfaces of the electrode which are in contact with the liquid electrolyte. Hence, at least for the present practical purposes, it can be assumed that only the wetted (including flooded) zones of an electrode can possibly contribute significantly to its operating capacity.

During recent years, the "thin-film" model for gas diffusion electrodes seems to have gained preference over competing models such as the "simple pore" model, and not without basis. On this basis, one immediately concludes that the essential electrochemical reactions can then take place at practical rates only within the immediate vicinity of the interface between the dry and flooded zones of an electrode: that is, in the wetted, but not flooded zones. The truth, however, is that the relative importance of the wetted and flooded reaction zones may be expected to vary with the electrode structure and with operating conditions.

Studies on large pore electrode models (1, 2, 3) have shown that the main contribution to the current produced by an electrode is, indeed, from the exposed (i.e., wetted but not flooded) reaction zone. Without even considering the submerged (i.e., flooded) reaction zone, analytical predictions are in good agreement with experimental data. Moreover, optical studies (4) of the exposed reaction zones of flat and cylindrical non-porous electrodes have proved the existence of a thin electrolyte film which extends along the unsubmerged

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solid surface for a considerable distance beyond the apparent or visible meniscus, with the major reaction activity predominantly taking under this film and just beyond the apparent meniscus.

However, the theoretical treatment of operating porous electrodes is still far from being complete or generally applicable. That is to say, considerations have been given separately to both the submerged reaction zone (6,8) and to the exposed reaction zone (5, 6,7,8). While the resulting theoretical models correctly predict parameter relationship trends, quantitative agreement with experimental data is usually not good nor general. It has, therefore, become clear that merely scaling-down theoretical models adequate for large pore electrodes will not necessarily produce models suitable for practical, small pore electrodes. The electrolytic films on the walls of large pores are simpler in nature than those existing within electrodes consisting primarily of small pores. For example, because of capillary forces, small pore electrodes do not have, proportionally, as extensive exposed (wetted) reaction zones as those of large pore electrodes and, consequently, as the pore radii decrease, the contribution of the submerged (flooded) reaction zone must increase. Therefore, for porous electrodes with wide distributions of pore sizes, one must assume that both the exposed and submerged reaction zones may contribute significantly to the total current produced within an operating electrode, and the analytical model presently being tested attempts to take this adequately into account. Details of this model will be later reported along with the results obtained.

References to Appendix A

1) Will, F.G., J. Electrochem. Soc., 110, 145, 152 (1963)
2) Grens, E.A., Turner, R.M., and Katan, T., Ad. Energy Conversion 4, 109 (1964)
3) Bennion, D.N., and Tobias, C.W., J. Electrochem. Soc., 113, 589, 593 (1966)
4) Muller, R.H., ibid., 113, 943 (1966)
5) Iczkowski, R.P., J. Electrochem. Soc., 111, 605, 1078 (1964)
6) Austin, L.G. et al., I & EC Fundamentals, 4, 34 (1965)
7) Rockett, J.A., and Brown, R., J.Electrochem. Soc., 113, 207 (1966)
8) Wasan, D.T., Schmidt, T., and Baker, B.S., A.I.Ch.E. Symposium 25, Paper 25B, Detroit, Mich. Dec. 1966.

APPENDIX B

Experimental Facilities

The basic experimental facilities being provided for controlling and monitoring the performance of electrochemical systems under study comprise two main categories: 1) facilities for providing, controlling, and measuring the reactant, product, and purge flow streams (hereinafter referred to as the "flow facilities") and 2) facilities for controlling and measuring the electrical parameters (hereinafter referred to as the "electrical measurements facilities"). The former are schematically represented in Figure B-1 and the latter in Figure B-2. In addition, a precision oven is provided to maintain precise temperature control of the fuel cell (or other electrochemical device) being studied.

The flow facilities provide for precise measurement (and control) of all pertinent flow rates, pressures, pressure differentials, and temperatures. A multipoint temperature recorder provides for continuous monitoring of the latter. Precise temperature measurements are made by means of calibrated thermocouples and a precision digital voltmeter (referred to below) and/or a precision indicating potentiometer.

The product water vapor from the cell is collected in a steady-state manner by means of a small air-or-water-cooled jacketed glass condenser and a calibrated receiver.

Inert impurities in the reactant gases, which may accumulate in the reactant and water "cavities" of a fuel cell during extended operation, can either be removed by periodic purging or else simply maintained at arbitrary maximum levels by means of the continuous, controlled purge system provided.

Further details regarding individual items of equipment making up the flow facilities are given in Table B-1.

Precise voltages and currents (and any other parameters, such as temperatures, which can be sensed as e.m.f.'s) are conveniently measured and recorded by means of the 25-channel digital voltmeter data acquisition system. It is anticipated that IR-free cell and half-cell voltages will be routinely measured with the aid of a Kordesch-Marko interrupter circuit of modified design according to E.J. Cairnes and A.D. Tevebaugh (1) and a multipurpose storage oscilloscope. These results will be periodically checked using the pure D.C. interruption technique described by Trachtenberg (2) and Niedrach and Tochner (3).

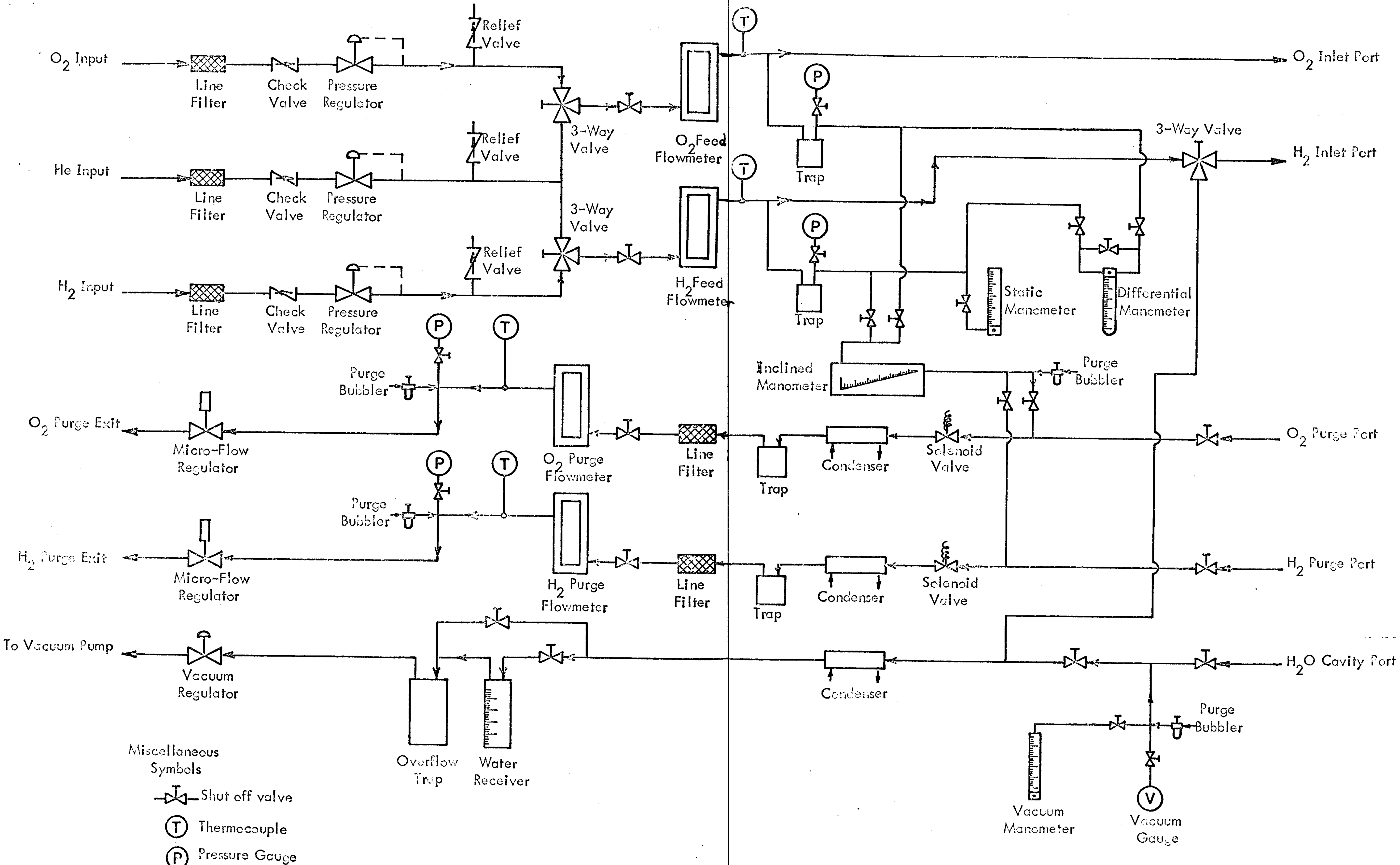
Details of the above electrical facilities are given in Table B-2, and details of some of the additional instrumentation to be later used for basic studies involving various voltammetric techniques earlier referred to are contained in Table B-3.

References to Appendix B

B1. General Electric Technical Summary Report No.3, Part I - Task IV, 1/1 to 6/30/63, Contract No. DA-44-009-ENG-4909, ARPA Order No. 247, Project No. 8A72-13-001-506, USAERDL.

B2. Trachtenberg, I., J. Electrochem, Soc., 111, 110 (1964).

B3. Niedrach, L.W. and Tochner, M, to be published (cited in General Electric Research & Development Center Report No. 66-C-194 (July 1966).



FOLDOUT FRAME 1

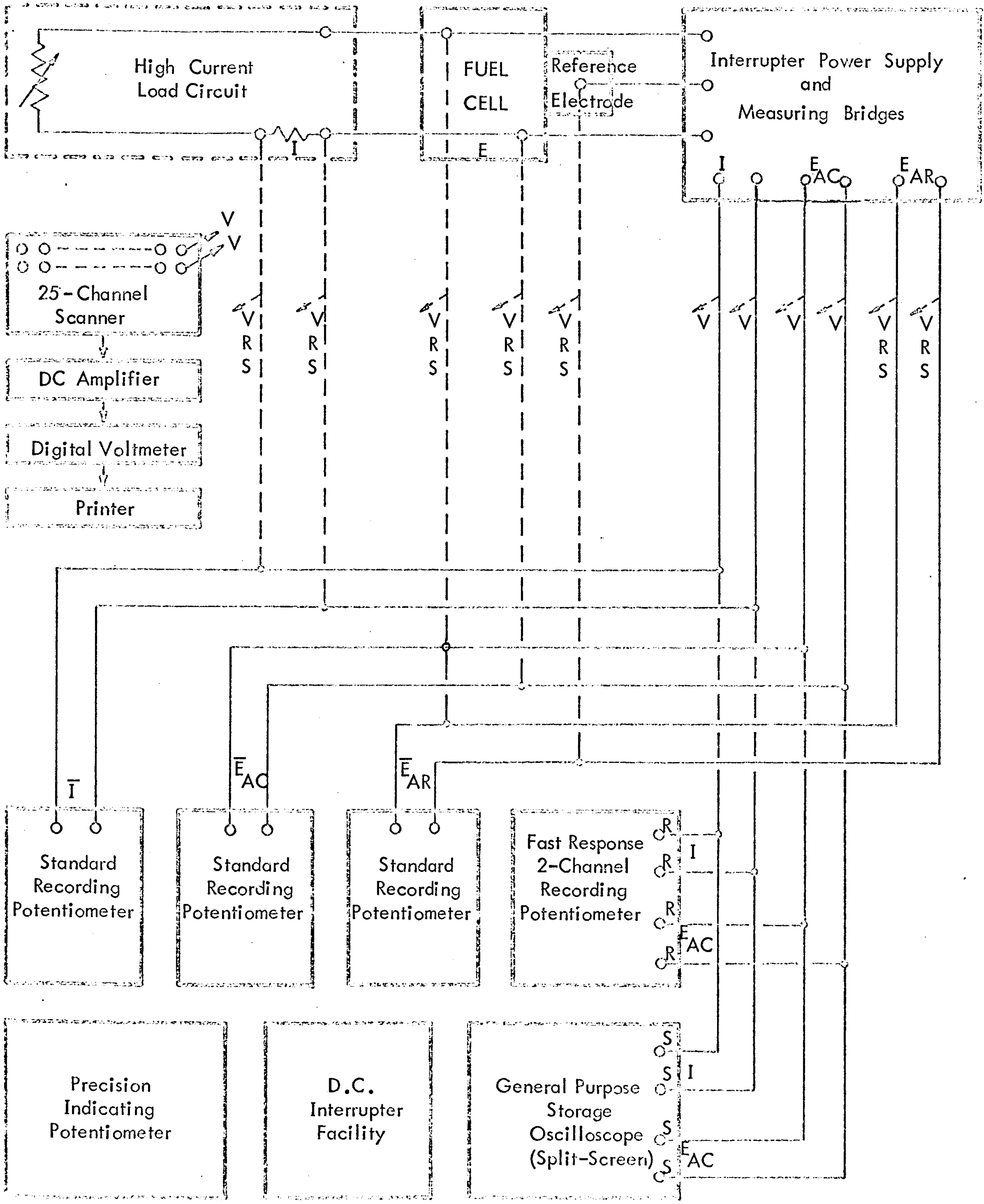
FOLDOUT FRAME 2

FIGURE B-1 FLOW FACILITIES FOR FUEL CELL EXPERIMENTS

Indicating Precision Potentiometer	L & N. Cat. No. 8686 Millivolt Potentiometer. Range: -10.1 mV to + 100.1 mV (for general use) 1.010V to 1.020V (for standard cell measurement) Accuracy: ± (0.03% of reading + 3 uV)
Modified Kordesch-Marko Interrupter and Measuring Bridge	Design according to E.J. Cairnes and A. D. Tevebaugh (Reference B-1)
Voltage Regulator	SORENSON Model 2000S. A.C. Voltage Regulator. Input: 95 to 130V, 50-60 cps, 27 amp. Output: 115V up to 2KVA Regulation accuracy: ± 0.1%

Table B-1. Flow Facility Items

Item	Description
Line Filters	Nupro 1/4" Inline Filters (7 μ pore size)
Check Valves	Nupro 1/4" Check Valves (Set at 25 psi)
Pressure Regulators	Matheson Model 8 Two-stage Regulators
Relief Valves	Nupro 1/4" Check Valves (Set at 50 psi)
3-way Valves	Hoke 1/4" 3-way Ball Valves
Flowmeters	Brooks Sho-rate 150 Calibrated Rotameters (R-2-15AA and R-2-15AAA tubes)
Micro-Control Valves	Brooks ELF Flow Controllers
Purge Bubblers	Meriam Sight Feed Bubblers (Also used as Traps)
Pressure Gauges	Robertshaw Acrogage Test Gauges (6")
Precision Absolute Pressure Gauges	Wallace & Tiernan Model FA 129 Absolute Pressure Gauges. 0 to 20.0 psia and 0 to 40.0 psia.
Static Manometers	Meriam Absolute Pressure Manometers (0-100" Hg)
Differential Manometer	Meriam U-tube Manometer (0-50" Hg, with alarm contactor)
Inclined Manometer	Meriam Inclined Tube Manometers (0-1" water)
Traps	Meriam Sight Feed Bubblers
Solenoid Valves	Hoke 1/4" Two-way Solenoid Valves
Condensers (3)	10" x 8 mm OD Pyrex tubing with 12 mm OD Pyrex jackets.
Condensate Receiver	Lab Glass Inc. Model LG-6480 Receiver (Capacity 100 ml).
Overflow Trap	Lab Glass Inc. Model LG-6500 Receiver (Capacity 1000 ml).
Shutoff Valves	1/4" Whitey#1 Series Valves (with Kel-F tips)
Vacuum Regulator	Conoflow H-20VT Vacuum Regulator.
Vacuum Pump	Precision Scientific Model PV-35.
Precision Oven	Blue M Model POM-206C Mechanical Convection oven. Saturable reactor proportioning control system Temperature range: to 343°C (650°F) Over-temperature protection.



FOLDOUT ~~FRAME~~ 1

LEGEND

I = Current Measurement

$\bar{I}$ = Time-averaged I

E = Overall Cell EMF

E_{AC} = Anode vs. Cathode EMF (IR-free)

$\bar{E}_{AC}$ = Time-averaged E_{AC}

E_{AR} = Anode vs. Reference EMF (IR-free)

$\bar{E}_{AR}$ = Time-averaged E_{AR}

V = Simultaneous tie-in with digital voltmeter

R = Optional tie-in with fast-response recorder

S = Optional tie-in with oscilloscope

Figure B2. BASIC ELECTRICAL MEASUREMENT FACILITIES

FOLDOUT FRAME 2

Table B-2. Basic Electrical Measurement Facilities

Item	Description
Digital Voltmeter	NON-LINEAR SYSTEMS Model 2917A Integrating Digital Voltmeter. Ranges: 120.000 mV to 1200.00V Accuracy on 1.2 V and higher ranges : ± 0.01% of reading ± 0.005% full scale ± 1 digit. Accuracy on 120 mV range: ± 0.02% of reading ± 0.01% full scale ± 2 digits. Input impedence: 0.1 to 10 megohms. Automatic polarity and range changing.
DVM Printer	HEWLETT PACKARD Model 561A. Digital Printer. Prints 11 digit columns at 5 lines/second.
DVM Scanner	25-Channel Stepping Switch Scanner (In-house fabricated). Manual, automatic, or programmable.
D.C. Amplifiers (2)	NEFF Type 119 DC Amplifiers. D.C. Gain: 1 to 1000 in fixed steps or variable. Gain accuracy: ± 0.01% DC gain stability: ± 0.005% full scale. Input impedence: 100 megohms minimum. Output capacity: ± 10 volts
Oscilloscope	TEKTRONIX Model 564 Storage Oscilloscope. Split screen storage. 3A3, 3A72, 3B3 plug-in units. Polaroid camera facilities.
Fast Response Recorder	BRUSH Mark 280 Model 15632701 Recorder. Dual 80 mm. wide channels. Ranges: ± 12.5 mV to ± 250V Input impedence: 1 megohm Inherent system accuracy: 1/2% Full scale response at 35 cps. 50% of full scale response at 60 cps 12 chart speeds: 0.05 to 200 mm/sec
Recording Potentiometers (3)	L & N Speedomax W Recording Potentiometers. Range: 0 - 10 mV Accuracy: ± 0.3% of scale span. Response time: 1 sec. for full scale travel. Dual chart speeds.
Indicating Self-Balancing Potentiometer	HONEYWELL ElectroniK Potentiometer. Overall Range: 0.001 mV to 160.100 mV Accuracy: ± 0.02% of span.

Table B-3. Auxiliary Electrical Measurement Facilities

Item	Description
Function Generator	WAVETEK Model 115 Function Generator. 0.0015 H_z to 1 MH_z Sine, square, triangle, and ramp wave forms. Trigger/phase lock. Voltage controlled.
Waveform Generators (2)	TEKTRONIX Type 162 Waveform Generators. Produces calibrated pulse, gate, and sawtooth outputs. Risetime: 1 μs minimum Duration: Pulse, 10 μs to 0.05s; Gate and sawtooth, 100 μs to 10s. Repetition rate: 0.1 Hz to 10kHz
Pulse Generator	TEKTRONIX Type 161 Pulse Generator. Produces calibrated rectangular pulses. Amplitude: 0 to 50V Risetime: $<$ 0.5μs to 1.5 μs Duration: 10μs to 100 ms Overshoot: $<$ 5%
Regulated Power Supply (for Tektronix generators)	TEKTRONIX Type 160A Power Supply.
Fast Rise Potentiostat	WENKING Model 61 RH Fast Rise Potentiostat (Tentative). Rise time: $< 10^{-6}$ sec. Voltage output: ± 40V Current range: ± 300 ma
Programmed Potentiometer-Controller for Potentiostat	WENKING Model MP 165. Motor Potentiometer (Tentative). Scan ranges: 0 to 1, 2, or 5V/hr. Scan rates: 1mV to 150V/hr Potential control stability: 0.002% of output.

APPENDIX C

New Flow-Through System Concept

Although remarkable advances have been made during the past decade in the development of technologies and understandings of fuel cell systems employing primarily gas diffusion electrodes - and additional studies aimed at obtaining increased basic and integrated understanding of such systems are still to be highly recommended - gas diffusion electrode systems have obvious inherent limitations. Supplying reactants and removing products to and from the active reaction sites of a gas diffusion electrode are governed mainly by the laws of static diffusion which at once drastically limit the maximum current densities attainable. Moreover, the effectively active reaction sites are generally confined to the immediate vicinity of the interface between the dry and flooded regions of an electrode, which not only further limits obtainable current capacities but also produces detrimental side effects such as local overheating and consequent accelerated aging and deterioration of electrodes.

"Flow-through electrode" schemes appear to offer considerable promise of ameliorating if not eliminating the above type limitations. In a typical flow-through system the electrolyte, first saturated with the appropriate reactant gas, is pumped through porous, catalytically active electrodes, whereby it becomes theoretically possible, at least, for the entire internal (and external) surface areas of the electrodes to be effectively active; and the mass transfer of reactants and products (and heat transfer) are no longer limited to molecular diffusional processes. On the other hand, the power required to pump the circulated electrolyte must be kept at a minimum in order not to nullify the direct or apparent gains in power output derivable from such systems. Obviously, two separate electrolyte streams are usually involved in flow-through electrode systems.

A flow-through (or flow-by?) hydrogen-oxygen fuel cell was apparently first constructed and studied by Bacon in 1939 (1). Bacon found that the output of his cell improved with increasing temperatures and pressures up to 240°C and 1090 psia (74 atm.). At the latter conditions, the output voltage was 0.65 volt at a current density of 75 amp./sq.ft. (81 ma./sq.cm.). Current density appeared to be limited by concentration polarization, probably because of the low solubilities of gases in KOH solution (27%) under Bacon's operating conditions. According to Zaromb's estimation (5), the solubilities of hydrogen and oxygen under these conditions are at most around 10^{-3} moles/liter, which would require an electrolyte flow rate of at least 15 gal./min. sq.ft. (1.02 cu.cm./sec. sq.cm.) in order to obtain a current density of 100 amp/sq.ft. (108 ma./sq.cm.). Consequently, the parasite power required to pump electrolyte was high enough to make this system impractical.

Meissner and Reti (2,3) recently investigated a flow-through system at room temperature and atmospheric pressure. Again, the low solubilities of hydrogen and oxygen at these conditions would again require inordinately large electrolyte flow rates for high power system operation.

By optimizing parameters independently, Reti and Sadek (4) concluded that the use of flow-through electrodes operating at electrolyte saturator pressures of 10 to 50 atm. would be advantageous over presently available fuel cell systems for mission durations up to 24 hours. The flow-through system appeared to have no advantages for longer missions.

Zaromb (5) recently performed a commendable preliminary conceptual design analysis of a hydrogen-oxygen flow-through fuel cell system based upon the electrolyte feeds being super-saturated with the respective reactant gases. The normal operating conditions assumed were: system and reactant saturator temperature, 75°C; system pressure, 10 atm; reactant saturator pressure, 200 atm.; electrolyte composition, 23% (5M) KOH. For a current density of 250 ma./sq.cm., the predicted output voltage was 1.10 volts/cell as compared to around 0.90 volts/cell for comparable gas-diffusion electrode systems or for low-to-moderate pressure saturated flow-through systems. Overall savings of 20 to 30% in total equipment and reactant weight were predicted for Zaromb's scheme, roughly independent of mission length.

The validity of Zaromb's analysis appears to hinge overwhelmingly upon the assumption that essentially negligible degassing of reactant gas will occur during the short time (ca. 0.5 sec.) required from the transfer of electrolyte from the saturators, maintained at 200 atm., to the system proper, maintained at 10 atm. It is a known fact that under conditions of extreme surface cleanliness, absence of foreign nuclei in the solution, and freedom from disturbances, supersaturated solutions of gases in liquids can indeed be maintained for considerable periods of time. Although all of these conditions will obviously not prevail in a practical fuel cell system, the required time durations are, by comparison, very small, so that the degree of degassing during these short periods may indeed prove not excessive. In any case, this appears to be the initial, major point which should be confirmed or disproved experimentally before significant additional engineering and/or research efforts be devoted to this concept.

Hence, the ability to maintain adequate reactant gas concentrations in the electrolytes being circulated is a primary criterion of practical feasibility of a flow-through system. Whereas the solubilities of gaseous reactants decrease with increasing temperature and increase with increasing pressure, the use of higher temperatures will simultaneously tend to decrease all three major polarizations likely to be involved in flow-through systems (i.e., activation polarizations, electrolyte ohmic polarizations and liquid-phase concentration polarizations) but increase possible corrosion problems, while the use of higher pressures will necessarily increase the weight of certain structural elements of the system, if not of the overall system. Consequently, there will be an optimum combination of operating temperatures and pressures for a given flow-through system.

The solubilities of hydrogen and oxygen under the above mentioned operating conditions are summarized as follows:

	Temperature	Pressure	O_2 Solubility (mole/liter)	H_2 Solubility (mole/liter)
Bacon	240°C	75 atm	10^{-3}	10^{-3}
Meisner & Reti	18°C	1 atm	2.0×10^{-4}	2.0×10^{-4}
Reti & Sadek	18°C	50 atm	1.0×10^{-2}	1.0×10^{-2}
Zaromb	75°C	200 atm	3.6×10^{-2}	3.4×10^{-2}
Proposed scheme	75°C	10 atm	1.6×10^{-2}	9.0×10^{-2}
Proposed scheme	75°C	50 atm	8.0×10^{-2}	4.4×10^{-2}

In the last two rows, gas solubilities are given for a new flow-through scheme employing "dispersed electrolyte" (i.e., an electrolyte in which a second liquid, essentially immiscible with the electrolyte but possessing a much greater solvent capacity for the reactant gases, has been dispersed or emulsified). In these cases, one volume of n-pentane dispersed in nine volumes of aqueous solution containing 23% KOH has been assumed. The electrical conductivity of the dispersed electrolyte would, therefore, be reduced by approximately 10%

relative to that for the corresponding pure aqueous electrolyte.

In order to derive net benefits from a flow-through system, it appears that the operating conditions must be such that gas solubilities close to 10^{-2} mole/liter can be obtained. That this requirement can be achieved at practical pressures and temperatures by the use of a dispersed electrolyte follows from the above table.

Figure C-1 shows schematically a half-cell flow-through apparatus to be constructed for studying the feasibility of the proposed concept employing dispersed electrolyte. The planned experiments will include studies of the effects of flow-through velocity, contact time, operating pressure and temperature, electrolyte composition, emulsifying agents, etc., upon half-cell performances. No attempt will initially be made to operate an apparatus at the still relatively high pressures likely to be required with a practical device. Both cathode and anode half-cell studies are planned. Based upon the data obtained, a single flow-through cell capable of operation at practical pressures would be constructed and tested for the purpose of demonstrating and evaluating the ultimate feasibility of this concept.

References to Appendix C

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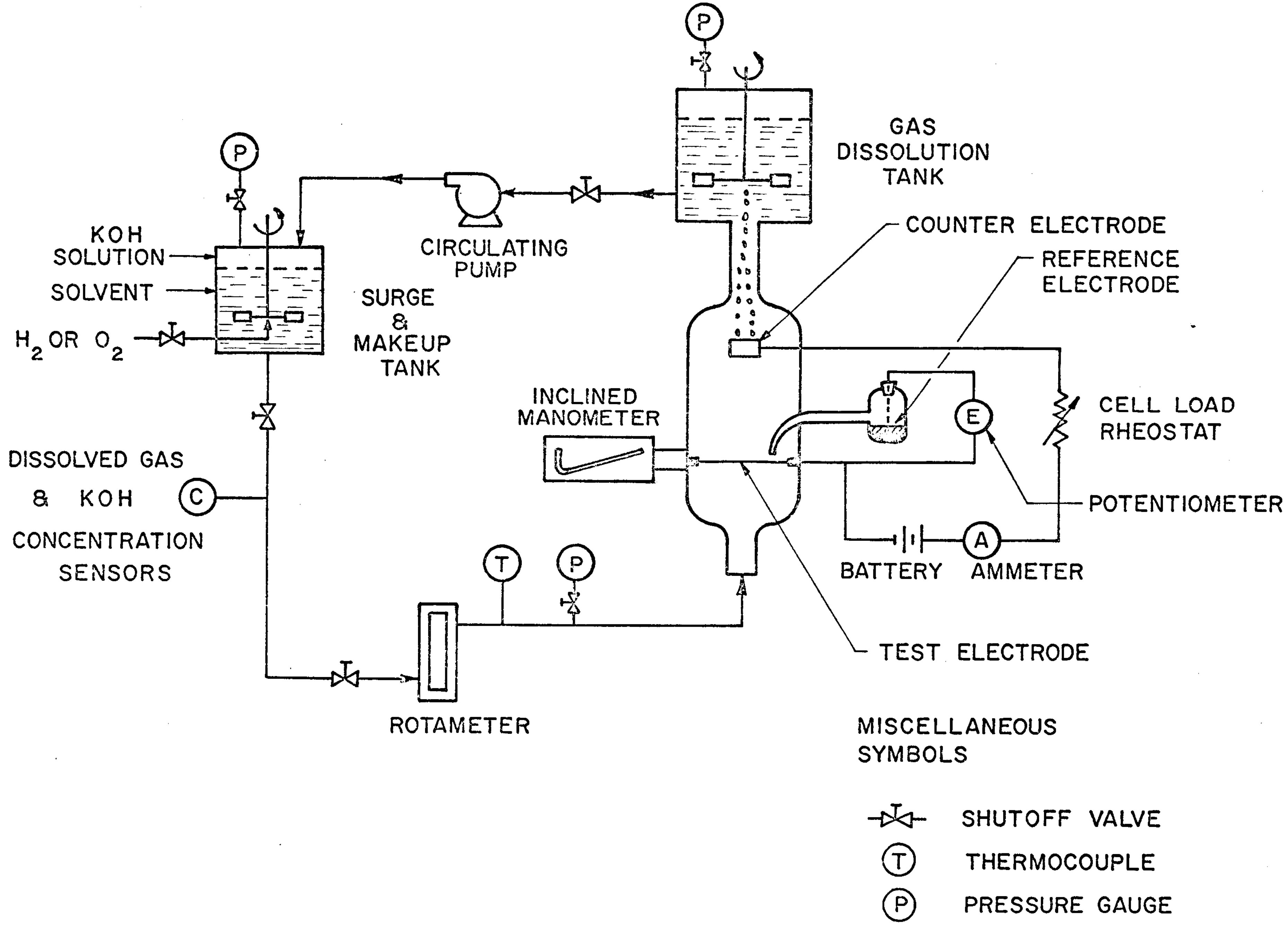

FIGURE C-1. SIMPLIFIED FLOW DIAGRAM FOR HALF-CELL FLOW-THROUGH EXPERIMENTS