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TOPICAL REPORT
FUEL CELL MEMBRANE ELECTRODE CONFIGURATION

31 August 1964

Prepared Under

Contract No. DA-49-186-AMC-166(X)
"Research to Improve Electrochemical Catalysts"

For

United States Army Materiel Command
Harry Diamond Laboratories
Washington, D. C. 20438

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ABSTRACT

A new method of fabricating fuel cell membrane electrodes has been developed which yields polytetrafluoroethylene-containing, platinum-black catalyzed electrodes which are highly active as hydrogen, hydrazine, methanol and propane anodes and as oxygen cathodes. The electrochemical activity of these membranes together with the activity of carbon-black polytetrafluoroethylene membranes of similar structure has been measured in half-cell and full-cell experiments. The membranes containing carbon black appear to be promising as support structures for metal chelate catalysts. The electrode fabrication technique is simple and appears to be applicable to many other combinations of fuel cell catalyst or catalyst support powders and hydrophobic binder materials.

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I. INTRODUCTION

One objective of the current chelate fuel cell catalyst program is the development of standard electrode substrates that yield optimum electrochemical activity when used as supports for the metal chelate catalysts. In the course of the development of these standard substrates, electrodes have been fabricated that show exceptional electrochemical activity with noble metal catalysts. Although complete characterization as to performance and life of these electrodes has not been made, results to date appear to be of sufficient interest to warrant a full disclosure at this time.

The author would like to acknowledge the contributions to this work of Dr. John O. Smith of Monsanto Research Corporation as well as the technical guidance and encouragement of Mr. Raymond H. Comyn and Dr. Gwendaline B. Wood of the Harry Diamond Laboratories, United States Army Materiel Command.

II. BACKGROUND

In attempting to fabricate a standard fuel cell electrode support for evaluation of chelate catalysts, the following desirable characteristics of a substrate have been considered:

(1) Contribution of maximum degree of three-phase (gas, electrolyte, and catalyzed electrode surface) contact, preferably without requiring precision control of pressures and temperatures in the fuel cell.

(2) Capability for adsorbing and holding the chelate catalysts in regions of the three-phase contact.

(3) Possession of high electrical conductivity, conducting electrons between the external circuit and the catalytically reacting chelate.

(4) Impermeability to the electrolyte (i.e., hydrophobic in the case of aqueous electrolytes).

(5) Favorable mechanical strength and reasonable flexibility to facilitate fuel cell assembly.

(6) Thermal stability.

(7) Amenability to fabrication in large area sheets with relatively uniform properties.

(8) Utilization of relatively inexpensive materials.

The problem of fabricating an electrode support membrane has been approached by first preparing and attempting to optimize the structure of electrodes containing known electrochemically active catalysts and then attempting to duplicate the configuration of these electrodes using potential support materials for the chelate compounds. Platinum black has been used as one of the known catalysts, with the expectation that an electrically conducting carbon black could be substituted in the fabrication of chelate support membranes. Polytetrafluoroethylene has been used as a binder and hydrophobic agent in these electrodes.

III. ELECTRODE FABRICATION

Continuous films containing platinum black and polytetrafluoroethylene in a 1-to-1 volume ratio have been fabricated using polytetrafluoroethylene in a water dispersion*. This form of polytetrafluoroethylene appears to have binding qualities for the platinum particles superior to those of dry Teflon-type polytetrafluoroethylene powder. Mixtures of platinum black, polytetrafluoroethylene and water, in proportions approximating those listed in Table 1, yield elastic, high viscosity agglomerates at room temperature that can be rolled into continuous membranes with thicknesses from 0.001 inch up. These membranes, after drying and suitable heat treatment up to about 300°C, yield electrodes with about 90 per cent porosity (formed by the displaced water) and with a surface area of exposed platinum of about 1.8 $m^2/in.^2$ for a sample film about 0.003 in. thick, containing about 60 mg of $Pt/in.^2$ These membranes have a fair amount of mechanical strength and are highly flexible without fracture or loss of material. For incorporation into a fuel cell or test electrode, the wet membranes are pressed into a wire screen current collector before drying and heat treatment.

Electrode membranes containing a 1-to-1 volume ratio of carbon black and Teflon-type polytetrafluoroethylene have also been fabricated by a procedure identical with that used to make the platinum polytetrafluoroethylene electrodes. The physical properties of a typical carbon polytetrafluoroethylene membrane are also summarized in Table 1.

The basic manufacturing process, then, consists in mixing the catalyst and/or conducting filler with the Teflon dispersion and water, limited mulling to form a mass of rubberlike consistency, rolling to desired membrane thickness, application to screen or other current collector material, and final drying and heat treatment.

Heat treatment will vary depending on the type of filler employed and the proportions of binder and filler. Electrodes described in this report were treated as follows:

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* Teflon type polytetrafluoroethylene dispersion in water, Dupont No. 852-201.

Table 1

COMPOSITION AND PHYSICAL PROPERTIES OF ELECTRODE MEMBRANES

	Platinum Membrane			
	% by Wt		% by Vol	
	Solids	Mix	Solids	Mix
Platinum	90	45.5	50	4
Polytetrafluoroethylene	10	4.6	50	4
H_2O	-	50.0	-	92

Typical Platinum-Polytetrafluoroethylene membrane
Thickness ≈ 0.003 in.
Platinum content ≈ 60 mg Pt/in.^{2} (20-30 m^2/g Pt)
Surface area ≈ 1.8 m^2/in.^{2} of membrane

	Carbon Membrane			
	% by Wt		% by Vol	
	Solids	Mix	Solids	Mix
Carbon black	50	16.6	50	8.3
Polytetrafluoroethylene	50	16.6	50	8.3
H_2O	-	66.8	-	83.4

Typical Carbon-Polytetrafluoroethylene membrane
Thickness ≈ 0.005 in.
Contains ≈ 50 mg carbon/in.^{2} (≈ 75 m^2/g C)
Surface area ≈ 4.0 m^2/in.^{2} of membrane

(1) Room temperature drying for 3-12 hours.
(2) One hour heat treatments at 100, 200, and 300°C.

No complete characterization of electrode materials or intermediate processing stage physical properties have been made; and therefore it is not yet possible to more precisely describe the manufacturing process.

IV. ELECTRODE TEST PROCEDURE

Two types of tests were conducted on the electrode membranes. They were tested in half-cell units for activity as anodes for the oxidation of hydrogen, propane, hydrazine, and methanol and as cathodes for the reduction of both pure and atmospheric oxygen. Both potassium hydroxide and phosphoric acid were used as electrolytes in the half-cell work. Two electrodes were also tested in a hydrogen-oxygen full cell.

For the half-cell tests, electrode membranes were prepared and pressed into electrode brackets as shown in Figure 1. Tantalum brackets were used for tests conducted with acid electrolytes and nickel brackets for those conducted with caustic electrolytes. Although the electrode brackets provide about 6.45 cm^2 of exposed electrode surface, all but 1 cm^2 of the surface of each electrode was masked off with treated Teflon washers in each test*.

The half-cell test unit is shown in Figure 2 and the accompanying circuitry in Figure 3. In the test cell the tip of a Luggin capillary was spaced about 1.5 mm from the electrode face in the electrolyte. In general, the tests were conducted without fuel gas breakthrough through the electrode, although a few of the membranes tested leaked electrolyte, necessitating breakthrough operation. In those tests conducted without breakthrough, a continuous flush of fuel gas or oxygen was maintained across the electrode surface.

Two sets of voltage readings were taken in each half-cell test. These were the actual potential between the electrode and the reference electrode, including the IR losses, and a Kordesch-Marko bridge potential reading free of IR losses**. The bridge generally used was limited to currents of about 500 ma so that this was the maximum current tested on most electrodes. A few tests in the highly conductive electrolytes were extended as far as 900 ma with other equipment.

The full-cell design is shown in Figure 4. The area of the electrodes tested in this cell was about 37 cm^2. Only the voltage produced by the cell, including IR losses, was measured. Moisture balance was obtained by manual control of fuel and oxidant flow rates.

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* Except Electrode No. 60456-I as noted in Table 2.

** Kordesch, K., and Marko, J. Electrochem. Soc., 107:6, 486 (1960).

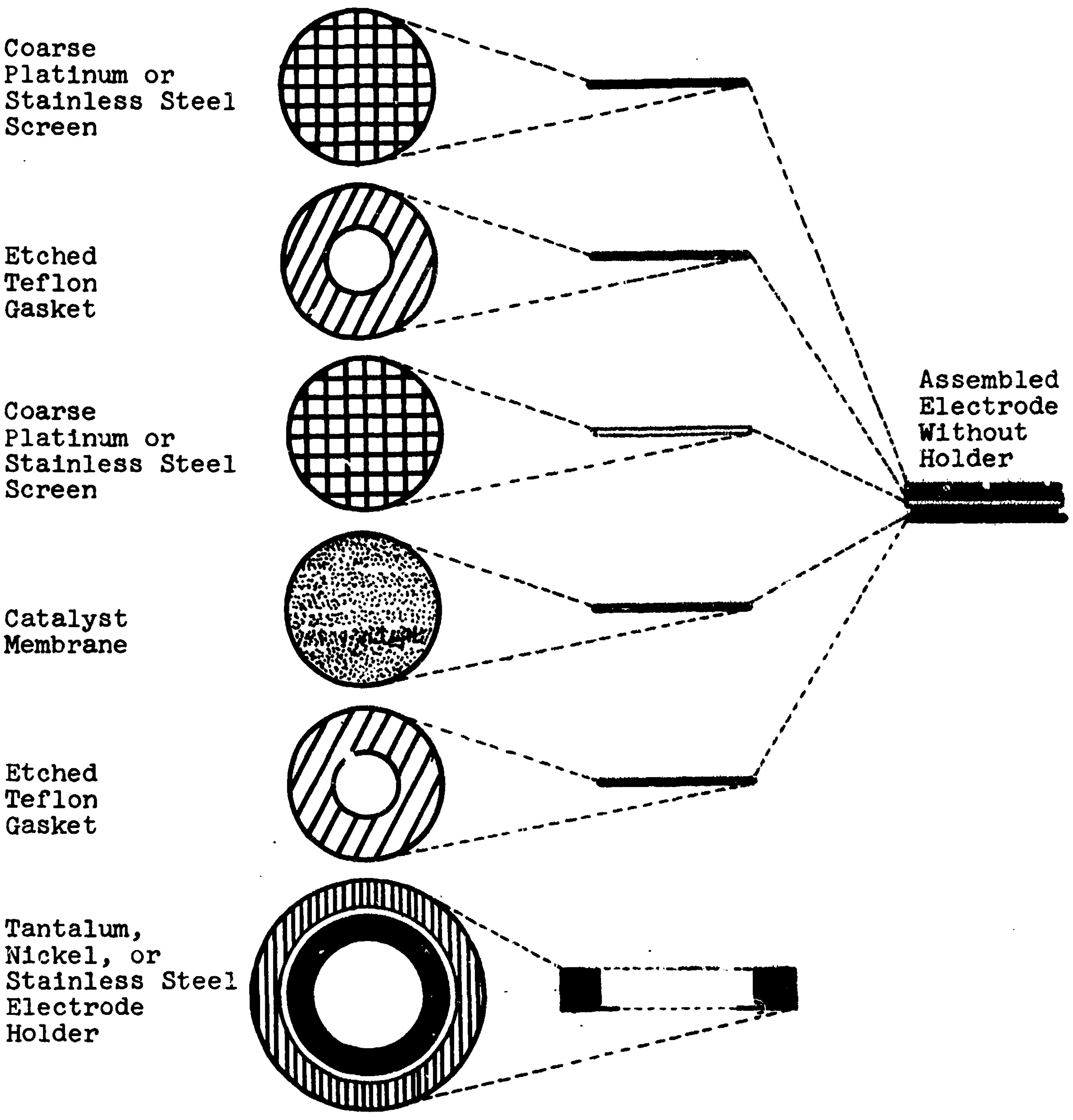

Figure 1. Exploded View of Half-Cell Test Electrodes

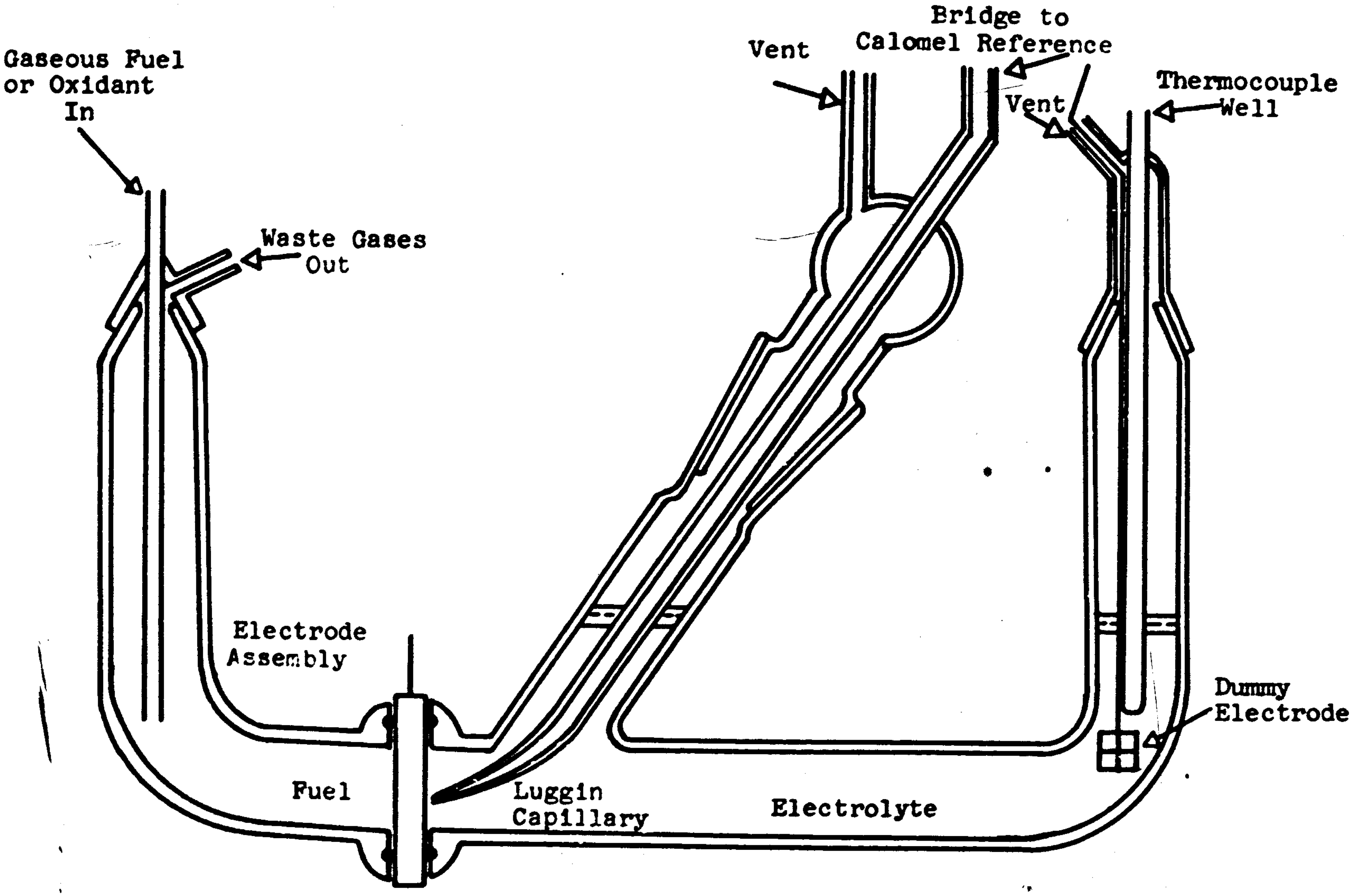

Figure 2. Side View of Half-Cell Test Unit

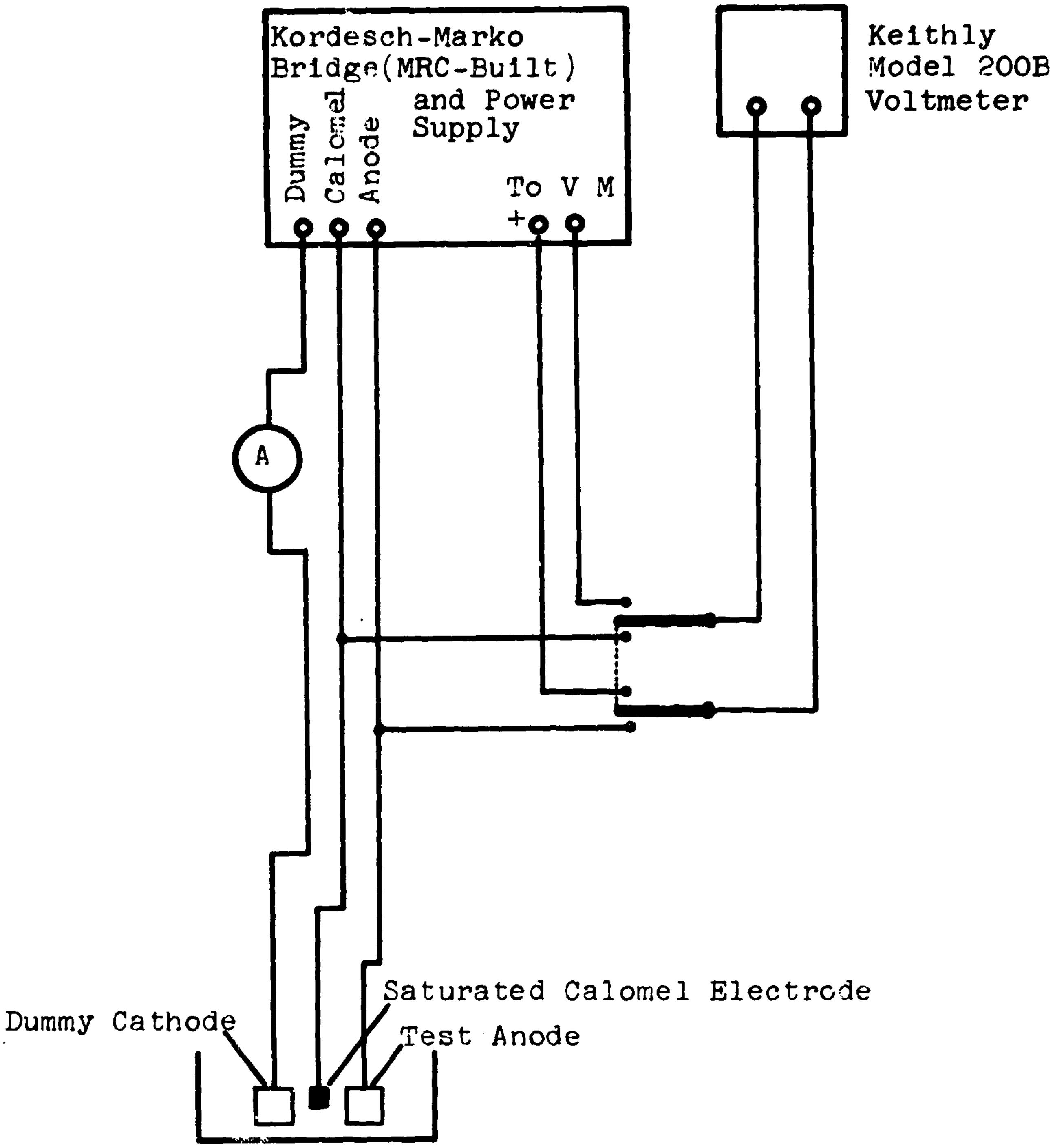

Figure 3. Anode Half-Cell Testing Circuit

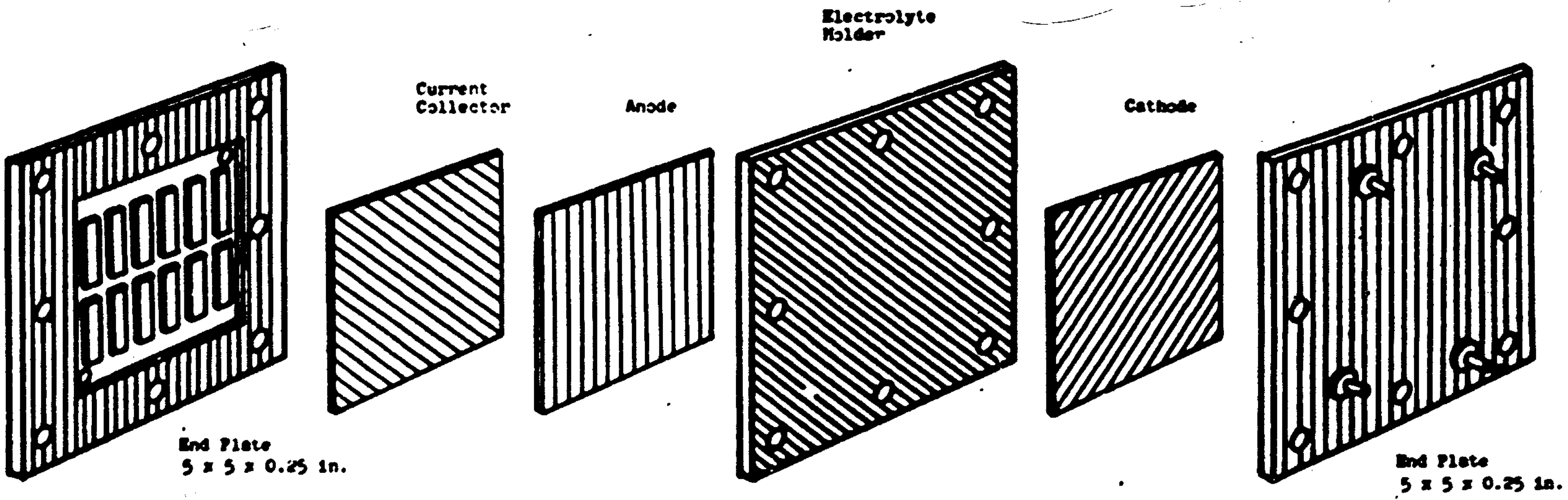

Figure 4. Full Cell -- 1/25 ft² Electrodes

V. ELECTRODE TEST RESULTS

A. HYDROGEN ANODE HALF-CELL TESTS

Several tests were made on the activity of the platinum-polytetrafluoroethylene membranes as hydrogen anodes. The results of these tests are shown in Table 2 and in Figures 5 and 6.

Tests were conducted in both 85% H_3PO_4 and 40% KOH at 25°C and 90°C. The open-circuit potentials were near the reversible hydrogen potential in each case. In 85% H_3PO_4 at 90°C the IR-free polarization from open-circuit potential was generally less than 0.05 volt at 500 ma/cm^2. In 40% KOH at 90°C the IR-free polarization was about 0.04 volt from open-circuit at 900 ma/cm^2. IR losses were generally high (0.3 to 0.5 volt at 500 ma/cm^2) in the poorly conducting 85% H_3PO_4 but were much lower ($\approx$0.09 volt at 500 ma/cm^2) in 40% KOH. The 25°C test results demonstrated much higher IR losses in 85% H_3PO_4, but generally only slightly more polarization than the corresponding 90°C tests in 40% KOH. One electrode operated in 85% H_3PO_4 was subjected to a 65-hour test at 246 ma/cm^2 at 25°C as noted in Table 2. Polarization data taken on this electrode before and after this constant current test show little degradation of its activity. Another electrode operated in 40% KOH at 90°C was subjected to a 24-hour test at 500 ma/cm^2. The IR-free polarization from open circuit at the beginning and end of this test was 0.08 and 0.15 volt respectively. The carbon-polytetrafluoroethylene membranes demonstrated no activity as a hydrogen oxidation electrode and were therefore not tested with the other fuels.

B. PROPANE ANODE HALF-CELL TESTS

The activity of the platinum-polytetrafluoroethylene membranes as propane anodes in 85% H_3PO_4 at 150°C is shown by the data in Table 3 and by the polarization curve in Figure 5. The open-circuit potential is about 0.13 volt more positive than the reversible hydrogen potential at 150°C. The polarization from open-circuit potential at a current density of 50 ma/cm^2 was generally about 0.3 volt. The potential rose sharply in a positive direction at current densities ranging from 50 to 200 ma/cm^2 on the 7 electrodes listed in Table 3. In constant current tests at 50 ma/cm^2 the electrodes maintained a potential of about 0.28 volt above the OCP for about one hour, at which time the voltage rose sharply. When the electrode was allowed to rest for a few minutes, the potential returned to the original OCP. In a subsequent constant current test at 50 ma/cm^2 the electrode maintained a potential 0.28 volt above the OCP for a much shorter time than in the original test, increasing with the length of time the electrode was allowed to rest at the OCP.

C. HYDRAZINE HALF-CELL TESTS

The activity of the platinum-polytetrafluoroethylene electrodes for hydrazine oxidation was demonstrated in a test conducted using a 95% H_3PO_4 electrolyte at 90°C and 100% hydrazine hydrate in the fuel side of the half cell. Data are shown in Table 4 and in Figure 5.

Table 2

HYDROGEN HALF-CELL TEST DATA ON PLATINUM-POLYTETRAFLUOROETHYLENE ELECTRODES

Electrode Area = 1 cm²

85% H_3PO_4 Electrolyte

Electrode Number	Test Reference		Potential vs SCE (volts) at 25°C ‡					Potential vs SCE (volts) at 90°C ‡					
			OCP	25 ma	100 ma	300 ma	500 ma	OCP	25 ma	100 ma	300 ma	500 ma	800 ma
60431	53097	IR*	-0.15	0.02	0.27	0.65	0.85	-0.13	-0.10	-0.03	0.15	0.33	
VI		KM**	-	-0.12	-0.12	-0.10	-0.08	-	-0.12	-0.12	-0.10	-0.10	
60432	53099	IR	-0.20	-0.08	0.09	0.60	0.88	-0.12	-0.09	0.01	0.24	0.44	
VII		KM	-	-0.17	-0.17	-0.16	-0.10	-	-0.10	-0.10	-0.10	-0.08	
60433	62301	IR	-0.16	-0.13	-0.05	0.24	0.46						
VIII		KM	-	-0.13	-0.15	-0.13	-0.11						
60434	62303	IR	-0.21	-0.06	0.08	0.45		-0.15	-0.12	-0.06	0.10	0.25	
IX		KM	-	-0.16	-0.16	-0.13		-	-0.11	-0.11	-0.09	-0.08	
60429	62305	IR	-0.13	-0.08	0.14	0.44		-0.13	-0.10	0.00	0.19	0.35	
III		KM	-	-0.13	-0.12	-0.11		-	-0.14	-0.13	-0.13	-0.11	
60434	62307	IR	-0.17	-0.14	-0.04	0.07		-0.13	-0.11	-0.07	0.05	0.11	
I		KM	-	-0.15	-0.14	-0.04		-	-0.10	-0.10	-0.09	-0.07	
60456†	60456	IR						-0.12	-0.11	-0.06	0.06	0.17	0.29
I		KM							-0.12	-0.12	-0.11	-0.11	-0.09
60456	60457††	IR	-0.18	-0.16	-0.08	0.13	0.30	-0.12	-0.10	-0.06	0.04	0.15	0.32
I		KM		-0.18	-0.16	-0.13	-0.07	-	-0.12	-0.12	-0.11	-0.09	-0.07

40% KOH Electrolyte

Electrode Number	Test Reference		Potential vs SCE (volts) at 25°C					Potential vs SCE (volts) at 90°C						
			OCP	25 ma	100 ma	300 ma	500 ma	OCP	25 ma	100 ma	300 ma	500 ma	700 ma	900 ma
60434	62309-	IR	-1.16	-1.13	-1.11	-1.03	-0.95	-1.12	-1.12	-1.11	-1.07	-1.02	-1.00	-0.95
IIa†††	62311-OR	KM	-	-1.13	-1.12	-1.10	-1.07	-	-1.12	-1.11	-1.11	-1.11	-1.11	-1.08

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‡ Saturated calomel electrode is at room temperature for all readings.

* IR -- Potential with half-cell IR loss included.

** KM -- IR-free potential obtained with Kordesch-Marko Bridge.

† Entire active electrode area exposed to the electrolyte, i.e., no electrode masking.

†† After 65 hours of operation at 246 ma/cm² at 25°C.

†††Life tested 24 hours at 500 ma: IR -- -0.95 v; KM -- -1.04 v.

Table 3

PROPANE HALF-CELL TEST DATA ON PLATINUM-POLYTETRAFLUOROETHYLENE ELECTRODES

Electrode Area = 1 cm^2

Electrode Number	Test Reference		Potential vs SCE * 85% H_3PO_4 Electrolyte (volts), T = 150°C								Constant Current Tests	
			OCV	10 ma	25 ma	50 ma	100 ma	150 ma	200 ma	300 ma	Current (ma)	Time (min)
60431	53090	IR	0.09	0.28	0.37	0.52	fell off	-	-		none	
IV		KM	0.06	0.22	0.28	0.41	fell off	-	-			
60431	53092	IR	0.07	0.25	0.30	0.35	0.45	0.55	fell off			
V		KM	0.04	0.20	0.25	0.27	0.34	0.40	fell off			
60431	53097	IR	0.07	0.22	0.26	0.33	0.41	-	0.56	fell off		
VI		KM	-	0.19	0.21	0.27	0.29	-	0.36	fell off		
60434	62303	IR	0.04	0.09	0.23	0.34	fell off	-			50	30
IX		KM	-	0.10	0.24	0.32	fell off	-			50	6
60429	62305	IR	0.09	0.19	0.27	0.33	0.44	fell off			100	7
III		KM	-	0.11	0.19	0.24	0.32	-			50	71
60434	62316	IR	0.04	0.18	0.30	0.35	0.44	fell off			75	30
IIIa		KM	-	0.18	0.29	0.32	0.36	fell off				
60440	63701	IR	0.06	0.17	0.27	0.35	0.40 (75 ma)	fell off				
IVa		KM	-	0.17	0.25	0.32	0.36	fell off				

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* Saturated Calomel Electrode is at room temperature for all readings.

Table 4

HYDRAZINE AND METHANOL HALF-CELL TEST DATA ON PLATINUM-POLYTETRAFLUOROETHYLENE ELECTRODES

Temperature = 90°C
85% H_3PO_4 Electrolyte
Electrode Area = 1 cm²

Electrode Number	Test Reference	Fuel Mixture		Hydrazine Potential vs SCE (volts)*				
				OCV	25 ma	100 ma	300 ma	500 ma
60431 V	53904	1M N_2H_4 in 42.5% H_3PO_4	IR	-0.07	-0.01	0.13	0.52	0.79
			KM	-	-0.08	-0.02	0.12	0.24
		1M HNO_3 and 1M N_2H_4 in 42.5% H_3PO_4	IR	0.05	0.10	0.27	0.53	0.72
			KM	-	0.02	0.04	0.12	0.23
		100% $N_2H_4 \cdot H_2O$	IR	-0.25	-	-0.06	0.17	0.40
			KM	-	-	-0.29	-0.22	-0.13

Electrode Number	Test Reference	Fuel Mixture		Methanol Potential vs SCE (volts)*							
				OCV	10 ma	50 ma	100 ma	200 ma	300 ma	500 ma	740 ma
60434 IIIa	60439	50% CH_3OH and 42.5% H_3PO_4	IR	-0.02	0.32	0.38	0.43	0.52	0.58	0.73	0.90
			KM	-	0.26	0.31	0.32	0.32	0.37	0.39	0.40
				OCV	100 ma	200 ma	400 ma	500 ma	750 ma		
		100% CH_3OH	IR	0.03	0.48	0.56	0.72	0.78	0.97		
			KM	-	0.41	0.42	0.44	0.44	0.45		

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* Saturated calomel electrode is at room temperature for all readings.

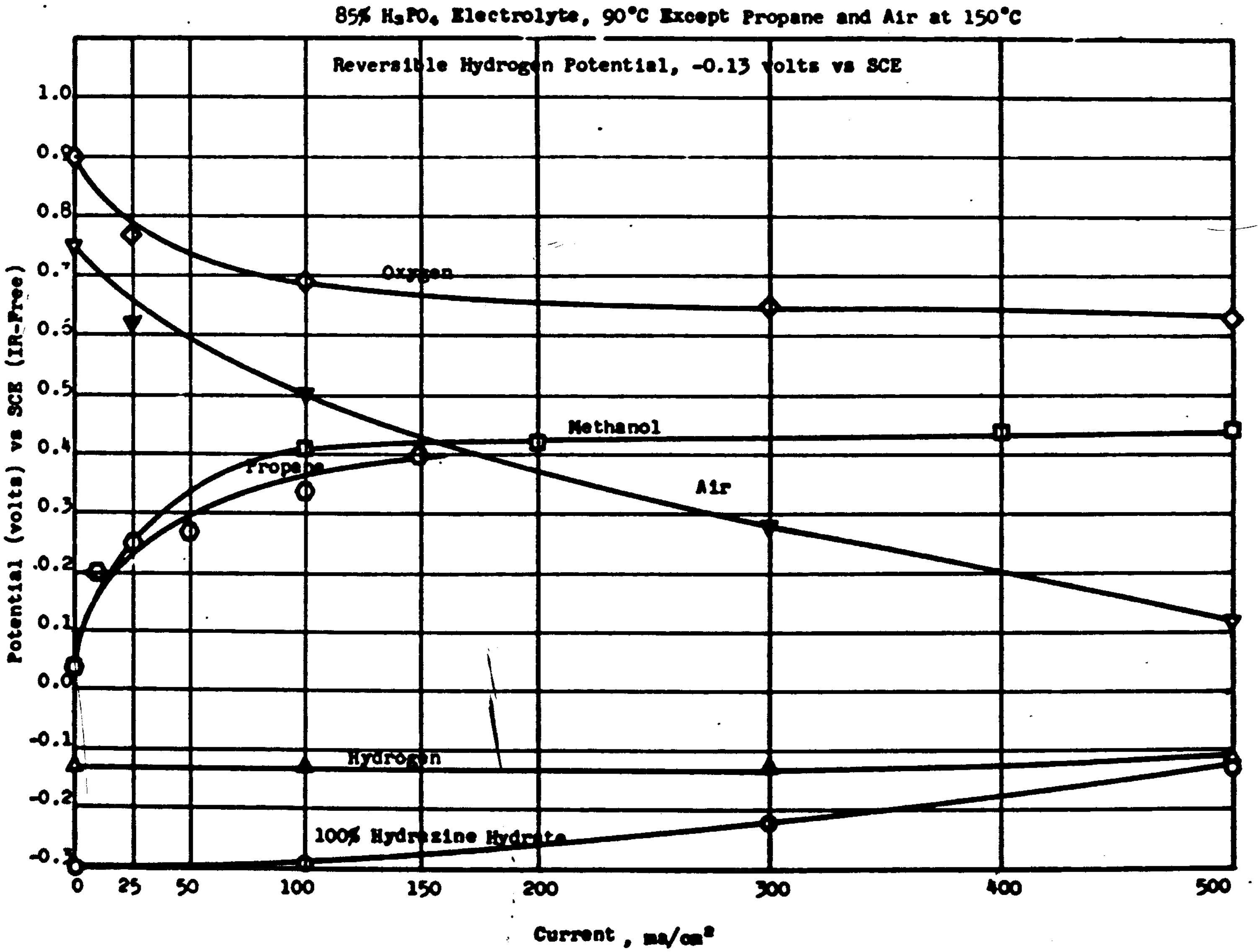

Figure 5. Half-Cell Electrode Performance of Platinum-Polytetrafluoroethylene Membranes for Various Fuels and Oxidants

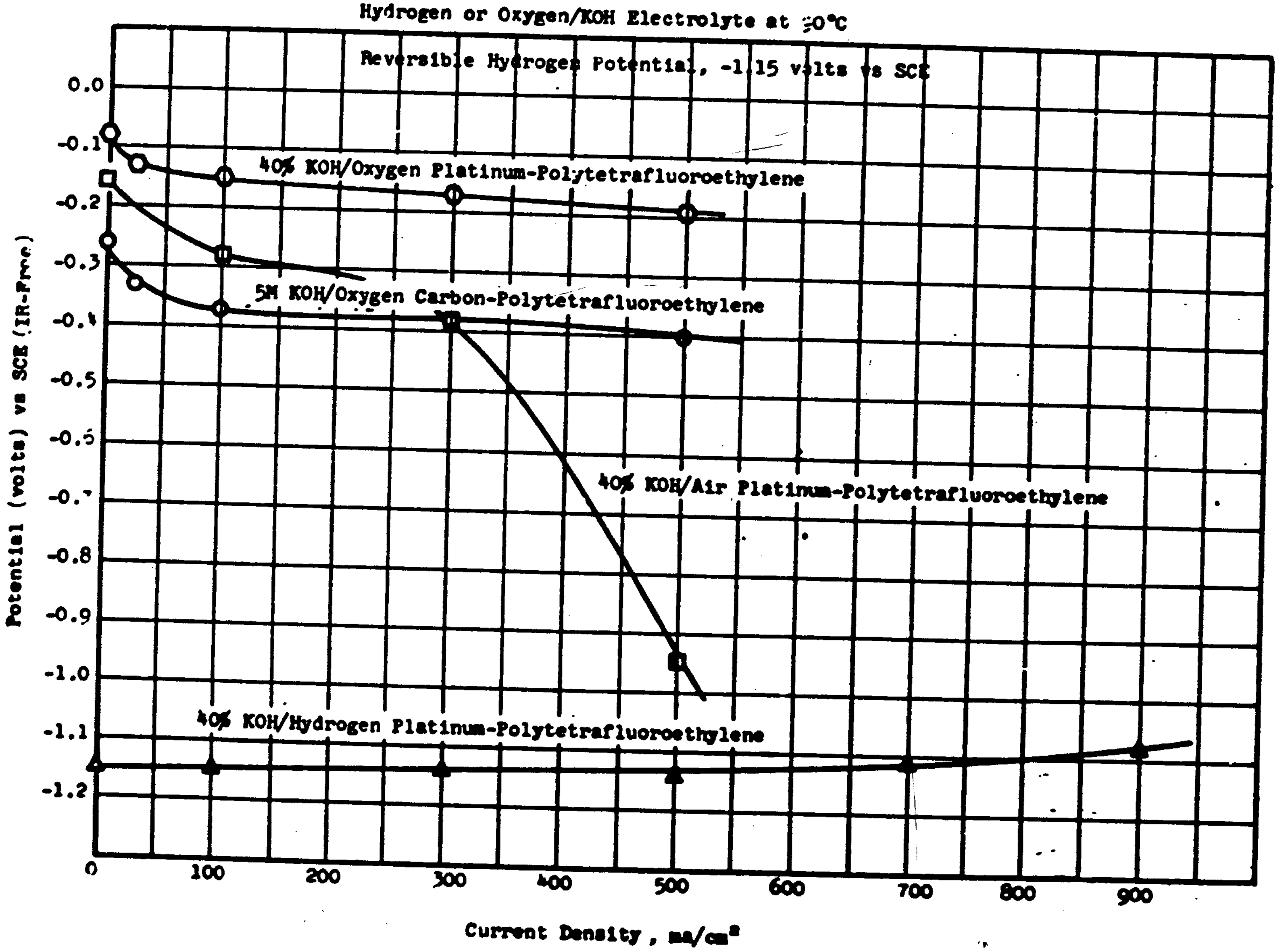

Figure 6. Half-Cell Electrode Performance of Electrode Membranes

The OCP was about 0.12 volt more negative than the hydrogen potential in this electrolyte. The polarization from open circuit at 500 ma/cm^2 was about 0.12 volt. Other tests were conducted using 1M N_2H_4 in 42.5% H_3PO_4 and in 42.5% H_3PO_4 containing 1M HNO_3. These tests showed higher polarizations from open circuit than the test conducted on 100% $N_2H_4 \cdot H_2O$. Nitric acid contamination increased the potentials obtained with the 1M N_2H_4 at low current densities (below 200 ma/cm^2) but did not affect the half-cell potentials at 300 to 500 ma/cm^2.

D. METHANOL HALF-CELL TESTS

The activity of the platinum-polytetrafluoroethylene membranes as electrodes for methanol oxidation using a 95% H_3PO_4 electrolyte at 90°C is shown in Table 4 and in Figure 5. The OCP with 100% MeOH fuel was about 0.16 volt more positive than the reversible hydrogen potential. After an initial polarization from open circuit of 0.38 volt at 100 ma/cm^2, the potential increased only an additional 0.04 volt up to 740 ma/cm^2. Using 50% MeOH fuel dissolved in 42.5% H_3PO_4 electrolyte improved the OCP by 0.05 volt and also decreased the polarization from open circuit. This resulted in potentials 0.10 to 0.05 volt more negative than those obtained with the 100% MeOH fuel at current densities from 100 to 740 ma/cm^2.

E. OXYGEN HALF-CELL TESTS

Both the platinum-polytetrafluoroethylene and the carbon-tetrafluoroethylene membranes were tested for their activity as oxygen electrodes in KOH and H_3PO_4 electrolytes. The results of these tests are indicated by the data in Table 5 and the oxygen curves in Figures 5 and 6.

A platinum-polytetrafluoroethylene membrane operating as an oxygen cathode in 40% KOH at 90°C gave an OCP 1.04 volts above the reversible hydrogen potential. The polarization from open circuit was 0.11 volt at a current density of 500 ma/cm^2. Using air as the oxidant under similar conditions gave an OCP 0.96 volts above the reversible hydrogen potential and a polarization from open circuit of 0.22 volt at 300 ma/cm^2. With 85% H_3PO_4 electrolyte at 90°C oxygen gave an OCP 1.03 volts above the reversible hydrogen potential. In this case the polarization from the OCP was 0.27 volt at 500 ma/cm^2. Utilizing air as the source of oxygen with 85% H_3PO_4 electrolyte at 145°C an OCP about 0.85 volt above reversible hydrogen was obtained with a decline to 0.47 volt at 300 ma/cm^2.

The carbon-polytetrafluoroethylene membranes operating on oxygen gave an OCP about 0.87 volt above the reversible hydrogen potential in 5M KOH at 90°C. The polarization from open circuit was about 0.15 volt at 500 ma/cm^2. At room temperature the OCP was slightly higher, but the voltages obtained with current flow are about the same as those obtained at 90°C. These electrodes appeared nearly inactive using an 85% H_3PO_4 electrolyte at 90°C, the OCP being 0.71 volt above

Table 5

OXYGEN AND AIR HALF-CELL TEST DATA ON ELECTRODE MEMBRANES

Electrode Area = 1 cm^2

Electrode Number	Test Reference		Electrolyte	Temperature °C	Potential vs SCE (volts)*					
					OCV	25 ma	100 ma	300 ma	400 ma	500 ma
			Platinum-Tetrafluoroethylene Membranes							
60434 IIa	62311	IR	40% KOH	90, O$_2$	-0.08	-0.14	-0.20	-0.26		-0.29
		KM			-	-0.13	-0.15	-0.17		-0.19
60434 IIa	62314	IR	40% KOH	90, Air	-0.16	-0.24	-0.31	-0.43		-1.05
		KM			-	-0.21	-0.28	-0.38		-0.95
60447 I	63711	IR	85% H$_3$PO$_4$	90, O$_2$	0.90	0.72	0.53	0.29		0.14
		KM			-	0.77	0.69	0.65		0.63
60434 IIIa	62316	IR	85% H$_3$PO$_4$	145, Air	0.75	0.61	0.44	0.07	-0.12	
		KM			-	0.62	0.50	0.28	0.12	
			Carbon-Tetrafluoroethylene Membranes							
60444 I	63706	IR	5M KOH	25, O$_2$	-0.14	-0.35	-0.47	-0.62		-0.72
		KM			-	-0.33	-0.35	-0.37		-0.38
		IR		90, O$_2$	-0.26	-0.33	-0.40	-0.50		-0.59
		KM			-	-0.33	-0.37	-0.38		-0.40
60444 II	63707	IR	5M KOH	25, O$_2$	-0.18	-0.45	-0.52	-0.65		-0.72
		KM			-	-0.20	-0.33	-0.34		-0.36
		IR		90, O$_2$	-0.25	-0.35	-0.41	-0.50		-0.57
		KM			-	-0.33	-0.36	-0.38		-0.34
60447 III	63713	IR	85% H$_3$PO$_4$	90, O$_2$	0.58	-0.02	-0.33	-0.45		-0.52
		KM			-	-0.05	-0.17	-0.23		-0.25

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* Saturated Calomel Electrode is at room temperature for all readings.

the reversible hydrogen potential and the polarization from open circuit being 0.53 volt at 25 ma/cm^2. The carbon-polytetrafluoroethylene electrodes have not been tested with air as the oxidant.

F. FULL-CELL TEST

Two platinum-polytetrafluoroethylene electrodes with an area of 37 cm^2 (0.04 ft^2) each were utilized as the anode and cathode in a hydrogen-oxygen cell. The cell was operated at 100°C with an electrolyte of 40% KOH contained in an 0.030-in. asbestos mat. The oxygen and hydrogen were supplied at atmospheric pressure.

The results of two current-potential tests conducted on this cell are shown in Figure 7. In the first test only the individual anode and cathode potentials (including IR losses) are indicated. There was some difficulty in operating the cell with an effective water balance during this test. Most of the decrease in cell voltage with increasing current resulted from a decrease in the cathode potential. The nearly linear nature of the cathode current-potential curve indicates that a great deal of IR loss may be included in the cathode potential values because of the geometry of the capillary to the reference electrode. The essential lack of anode polarization supports the half-cell data obtained earlier.

During a second test run on this cell a more effective water balance was maintained for a few hours, with a commensurate improvement in operation. The current full-cell potential curve (with IR losses) for this second run is shown in Figure 7. The cell delivered an OCP of 1.07 volts and from 175 to 200 watts/ft^2 of electrode area at current densities varying from 250 to 400 amp/ft^2 and potentials from 0.68 to 0.50 volt. This cell was operated for about 8 hours at a current output of 125 amp/ft^2 at a voltage of 0.80 volt.

VI. CONCLUSIONS AND RECOMMENDATIONS

The platinum-polytetrafluoroethylene membranes demonstrate excellent potential as hydrogen and hydrazine anodes and some potential as propane and methanol anodes. They also show some promise as oxygen electrodes. This potential has been demonstrated both in half-cell and full-cell data.

The carbon-black polytetrafluoroethylene membranes have some activity as oxygen electrodes. They appear highly promising as supports for anodically active chelate catalysts. This is indicated by their completely hydrophobic nature, their high surface area of carbon per unit area of membrane, and their activity as oxygen electrodes. This activity indicates that these membranes have the three-phase contact properties desired of an electrode support. These flexible membranes are simple to fabricate and are relatively inexpensive.

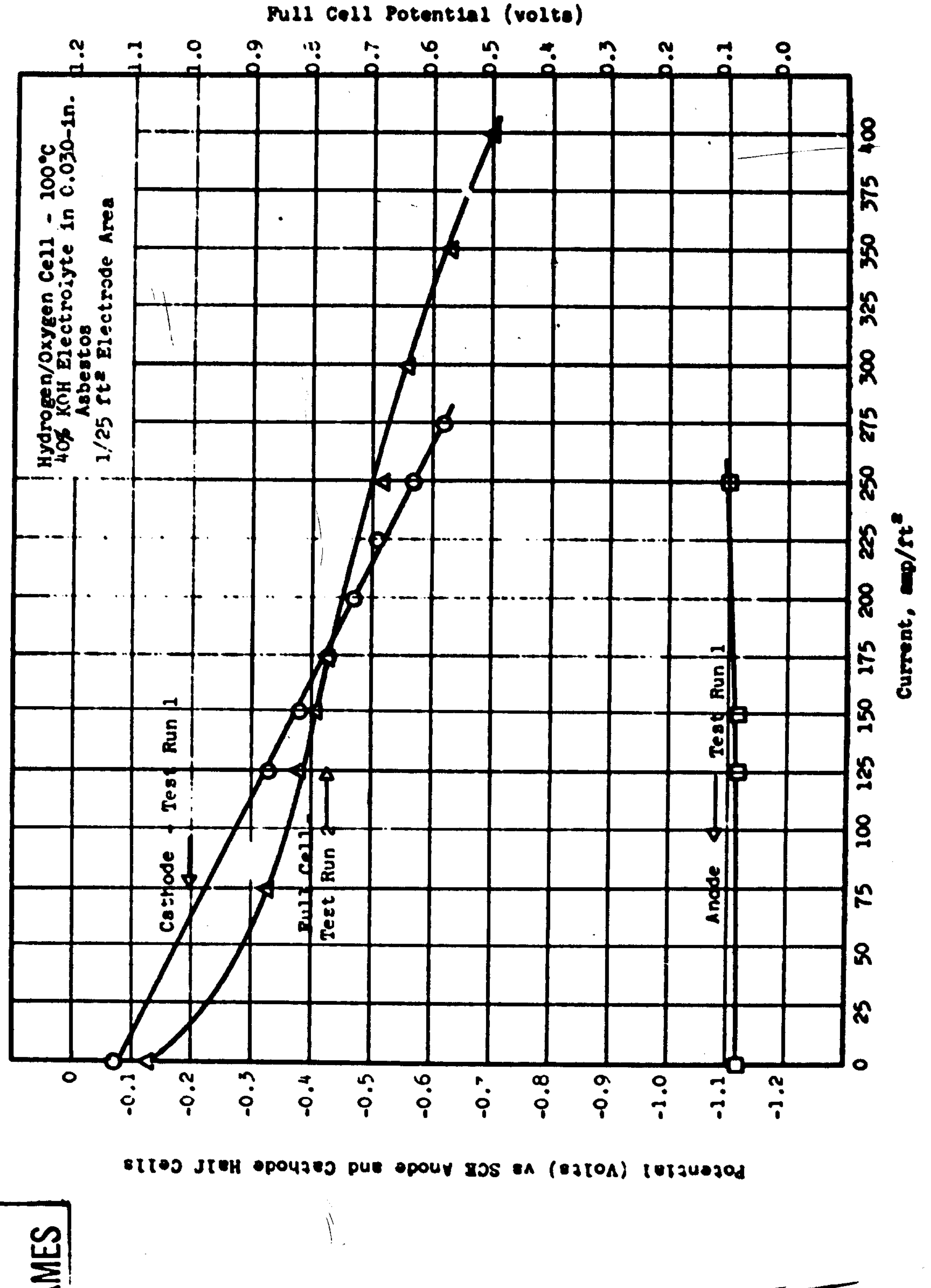

Figure 7. Full-Cell Performance of Platinum-Polytetrafluoroethylene Membrane Electrodes (Anode and Cathode)

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The electrode membrane fabrication technique developed in this work appears to have promise in many other electrode systems. Other high surface area solids can be incorporated in similar high surface area membranes by this technique, individually or in combination, both mixed and in laminar membrane structures. The surface areas of the carbon black and platinum black in the membranes discussed above are nearly identical with those of the pure powders, indicating that little of the surface of these powders has been covered by the polytetrafluoroethylene. This is true despite the fact that the powders are strongly bonded in the membrane structure and that no polytetrafluoroethylene is visible, even with an infrared detection device, on the membrane surface.

The electrode fabrication technique developed here should be applicable using hydrophobic binder materials other than polytetrafluoroethylene. It would appear that the organic materials and surfactants that stabilize the Teflon-water dispersion lead to the formation of elastic, rubberlike mixtures of water, polytetrafluoroethylene, and the catalyst or catalyst support powder at room temperature. It is the ease of fabrication of these elastic mixtures into thin continuous membranes by simple rolling or pressing operations and the highly porous structure remaining after removal of the volatile diluent (e.g., water) that make this electrode fabrication technique especially promising. Other combinations of high surface area hydrophobic powders, surface active agents, and other additives that give elastic mixtures with powdered solids may also yield stable, porous, electrode membranes.

In comparing the electrochemical performance of the electrodes described with performance of other electrodes described in the literature, the reader is cautioned to consider that no particular electrode optimizing effort has been undertaken in this work. It is quite likely that a concentrated development program on optimization of performance of this electrode type, particularly those catalyzed with noble metals, would result in improved operation.

No further work on noble-metal-catalyzed membrane electrodes is anticipated for this contract. Application of this electrode type to the testing of potential metal chelate electrocatalysts will be undertaken on the present contract and progress will be reported in the regular monthly and quarterly reports.