FEASIBILITY STUDY OF HIGH PERFORMANCE HYDROGEN-OXYGEN FUEL CELLS

Final Technical Report

by

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ESSO RESEARCH AND ENGINEERING COMPANY
Government Research Laboratory
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FOREWARD

This final technical summary discusses the results of feasibility studies of two novel H_2-O_2 fuel cell concepts conducted under National Aeronautics and Space Administration Contract NAS 7-529. This work was administered under the direction of NASA Headquarters, Washington, D.C.; Mr. Ernst Cohn was the Project Engineer for this program.

ABSTRACT

Two process concepts were examined to determine if decoupling the limiting cathodic process into its own reaction space could result in increased hydrogen-oxygen fuel cell efficiency and result in enhanced specific power. Although decoupling was successful with slurry catalyst and mediator systems, the anticipated performance improvements were not obtained.

Analysis of the slurry systems indicated that the moving bed concept introduced excessive parasitic pumping losses which significantly reduced power density and efficiency even under "idealized" conditions. The mechanical slurry system gave somewhat better results, yielding a specific power of 25 lb/kw. However, the overall efficiency was 53 percent, significantly below that of comparable conventional systems.

Work on the mediator concept indicated that the stack had good current capability, but the scrubber regenerator introduced a significant weight debit. Even with projected system improvements the best specific power obtained (500 lb/kw) is at least an order of magnitude poorer than conventional systems.

Detailed conclusions and recommendations are presented in Section V, pages 33 and 34.

ELECTROCHEMICAL REACTION ENGINEERING

SECTION I

INTRODUCTION

Hydrogen-oxygen fuel cell systems provide the highest power density configurations of all the present-generation fuel cell systems. However, significant improvements in power density and simplicity are required for increased mission capability and more extensive aerospace applications. Although further improvements can be expected when advanced laboratory electrodes are incorporated into existing systems, significant improvements will require new systems concepts if really lightweight power packages are to be obtained. This is due to the fact that all of the existing systems depend upon interface-maintaining or controlling electrodes which allow only a single reaction space in which to conduct many simultaneous physical and chemical reactions. All of these required reactions cannot be optimized in a single electrode geometry. Furthermore, the widely differing reactivities of the hydrogen anode ($i_o = 1$ ma/cm^2) and oxygen cathode ($i_o = 5 \times 10^{-8}$ ma/cm^2) would preclude the use of identical reaction geometry (as with present cells) without wasting the hydrogen anode capability. Thus decoupling (segregating) the limiting cathodic process into its own optimized reaction space offers a potential route to improved power density and efficiency.

Two process concepts have been devised to obtain the desired electrode decoupling. The first uses a circulating (cathode) catalyst slurry (coupled with a conventional anode) to transport oxygen from an optimized regenerator-absorber to the fuel cell stack,which performs only the non-limiting current collection and ion discharge functions. Thus, the "oxidized" catalyst serves as a pseudo-oxygen transport mediator. The second concept attempts to match the intrinsic reactivity of the anode through the use of an electrolyte soluble, oxygen regenerable redox couple with an i_o value equal to or greater than that of hydrogen. In this latter system, oxygen absorption in the regenerator-absorber is expedited due to the "instantaneous" reaction of the oxygen and the reduced mediator couple. The oxygenated couple is readily reduced at the fuel cell cathode, using a variety of catalysts, including platinum, gold and mercury.

This report discusses an engineering analysis program which was conducted to evaluate the technical feasibility of the moving bed and mediator hydrogen-oxygen fuel cell conceptual designs. The analysis of each system was conducted in two phases. In the first phase, the current collector space was analyzed to determine if the projected power density could lead to a practical system with enhanced performance. This was followed by a mass transport analysis of the regenerator-absorber unit (where indicated), and the polished conceptual designs were simulated using IBM 7094 and Quicktran 2 computers to determine optimum configurations and specific power (lb/kw). Details of this analysis are summarized in the following sections.

SECTION II

MOVING BED CATHODE FUEL CELL

As a result of previous analyses (1, 2), the first phase of this program was directed towards decoupling the anode from the diffusion limited cathode using a moving catalyst bed as the oxygen-charge carrier. The object of this analysis was to determine the feasibility of this approach to segregating the limiting (diffusion) step into its own optimized reaction space without introducing a systems imbalance. The concept of a moving catalyst bed is a direct offshoot of catalyst screening studies, where it is used to evaluate catalysts independent of the complicating factors of electrode structure or diffusion.

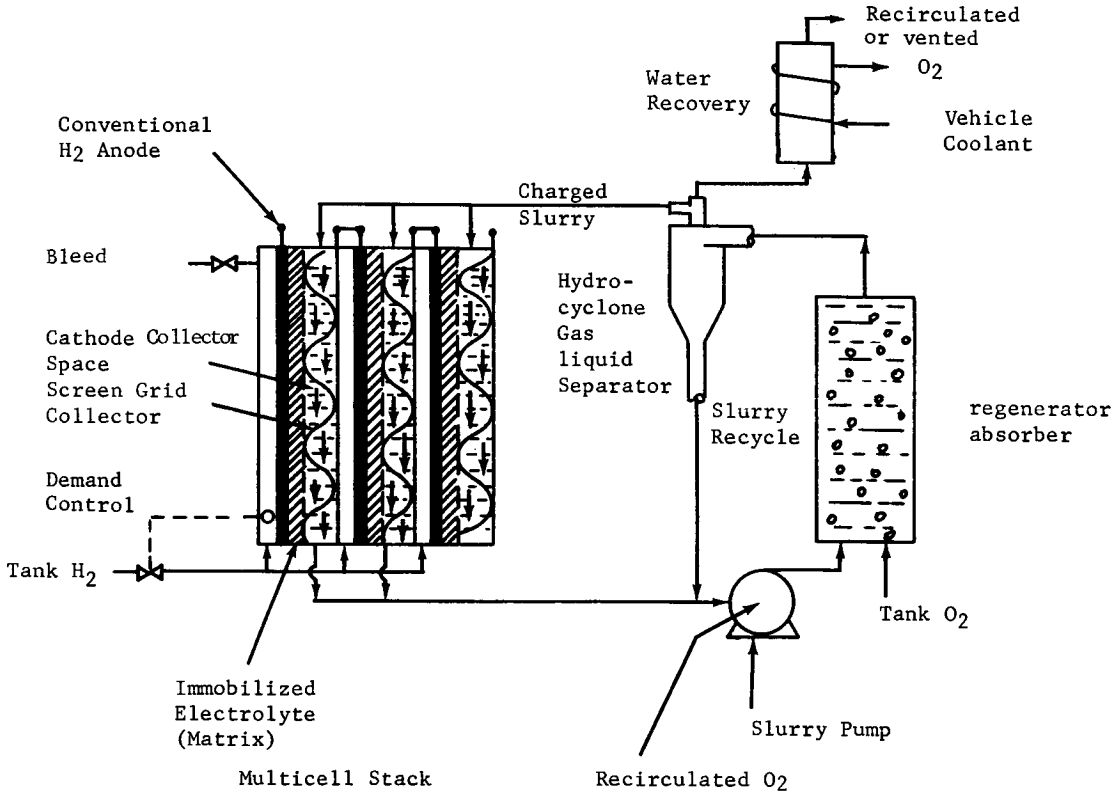
Figure 1 is a schematic of the moving bed cathode fuel cell concept used in this study. Starting at the gas-liquid hydrocyclone separator, the charged catalyst slurry is pumped into the electrode chamber where it impacts against the current collector screen. The contact resistance is assumed to be zero so that each contact results in a complete discharge of the particle to the collector grid potential. Since interparticle electron transfer is assumed to be negligible, the discharged particles leave the collector (cathode) space at a polarization η_e. The number of collector stages required is dictated by the fraction discharged per pass X_{out}/X_{in} and the hydrodynamic contact effectiveness, γ_t. The discharged slurry is pumped into the oxygen regenerator-absorber. The catalyst particle resides in the regenerator-absorber for a time θ_r sufficiently long to return to the charged catalyst polarization η through reaction with absorbed oxygen. This reaction serves to recharge the catalyst particle. Oxygen is injected into the regenerator-absorber co-currently to maintain the artificial "g" field induced by the slurry pump and hydrocyclone.

The anode system used in this conceptual design is a conventional interface maintaining hydrogen electrode backed by an asbestos matrix or "wettable" felt structure.

From the foregoing system description, one notes that the success of the moving bed cathode depends upon current collection efficiency (γ_t), contactor residence time (θ_r), and its relationship to the diffusion process in the regenerator.

FIGURE 1

SCHEMATIC OF MOVING BED CATHODE
HYDROGEN-OXYGEN FUEL CELL



Part a - Current Collection Model

Current collection in the moving bed cathode fuel cell is accomplished by impaction on a collection grid. The effectiveness of this collection process depends upon a number of hydrodynamic and electrochemical factors. Figure 2 shows a schematic of the current collector space showing a differential collector volume, dx, dy, dz, containing a unit collector surface ds. This collector surface is made up of a uniform distribution of grid stages perpendicular to the direction of slurry flow. The slurry containing z gms of catalyst/cm^3 enters at the bottom of the cell with velocity v cm/sec. If one assumes that:

- Collector screen grid can be approximated by a standard screen grid with a uniform distribution of collector surface per unit volume, and can be treated as discrete collection stages.

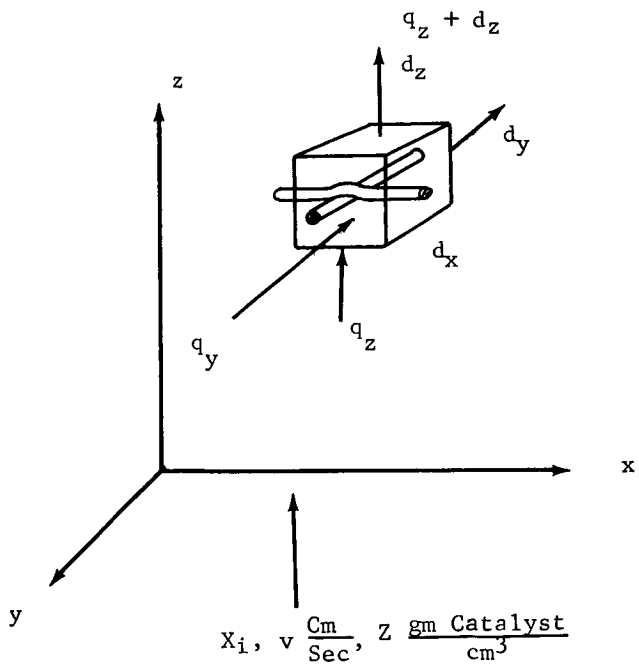
- Streamline flow exists on the leading edge of the collector but boundary layer separation is sufficient to product a "well mixed" system down-stream from a grid stage.

- Each contact of a catalyst particle and the grid results in a complete discharge to grid potential.
- Wall effects and inter-particle contact can be neglected, since impaction efficiency is low even when designed into the systems.
- The effect of velocity vector and energy distribution is incorporated in the contact efficiency term χ_t (Blodgett and Langmuir(3)).

A rational model for the collection grid system can be readily developed.

FIGURE 2

CURRENT COLLECTOR MODEL



q_x, q_y, q_z = Coulombic Flux, Coulombs/cm^2 sec

X = Fraction Charged Material Entering gm/gm total

The coulombic flux entering a stage is

$$q_z = (\eta_e - \eta) \; c \; v \; z \; X \; \frac{\text{coulombs}}{\text{cm}^2\text{sec}} \qquad (1)$$

where η_e is electrode polarization, η is polarization of the relaxed catalyst, c is capacitance, farads/gm, v is velocity, cm/sec, Z is catalyst concentration, gm/cm^3 and X is the fraction of charged material (gms charged/gm catalyst). Similarly, the coulombic flux leaving at stage z + dz is

$$q_{z+dz} = (\eta_e - \eta)\ c\ v\ z\ (X + dX) \quad \frac{\text{coulombs}}{\text{cm}^2\text{sec}} \tag{2}$$

and the charge entering the stage z collector wires is given by Equation 3,

$$q_x = \frac{-dq_z}{dz} = v\ ds\ z\ (\eta_e - \eta)\ c\ \gamma_t X \tag{3}$$

where γ_t is the hydrodynamic contacting efficiency which will be discussed later. A simple material balance across the element dx, dy, dz, yields,

$$v\ ds\ z\ (\eta_e - \eta)\ c\gamma_t X = -(\eta_e - \eta)\ c\ vz\ \frac{dX}{dz} \tag{4}$$

$$x\gamma_t\ ds = -\ da\ \frac{dX}{dz} \tag{4a}$$

Since da=dx·dy and A_f = ds/da (collection area per unit cross-section per stage) Equation 4a becomes,

$$\frac{dX}{x} = -A_f\gamma_t\ dz. \tag{4b}$$

Integration of Equation 4b (B.C. z = o, X = X_{in}) yields,

$$X(z) = X_{in}\ \exp -\ A_f\gamma_t Z. \tag{5}$$

Returning to Equation 3, the current collected per stage is,

$$\frac{dI}{dNda} = v\ A_f\ da\ Z\ (\eta_e - \eta)\ X\ (z)\ c\gamma_t, \tag{6}$$

where N is the number of collector stages in the cathode space, but $Q = v\int da$ (cm^3/sec) so that Equation 6 becomes,

$$\frac{dI}{dN} = Q\ A_f\ Z\ (\eta_e - \eta)\ X\ (z)\ c\gamma_t. \tag{6a}$$

Inserting Equation 5 into Equation 6a and integrating results in the following equation for the current collection space:

$$I\ (\text{amps}) = QZ\ (\eta_e - \eta)\ X_{in}\ \left[1 - \exp(-A_f\gamma_t N)\right] \tag{7}$$

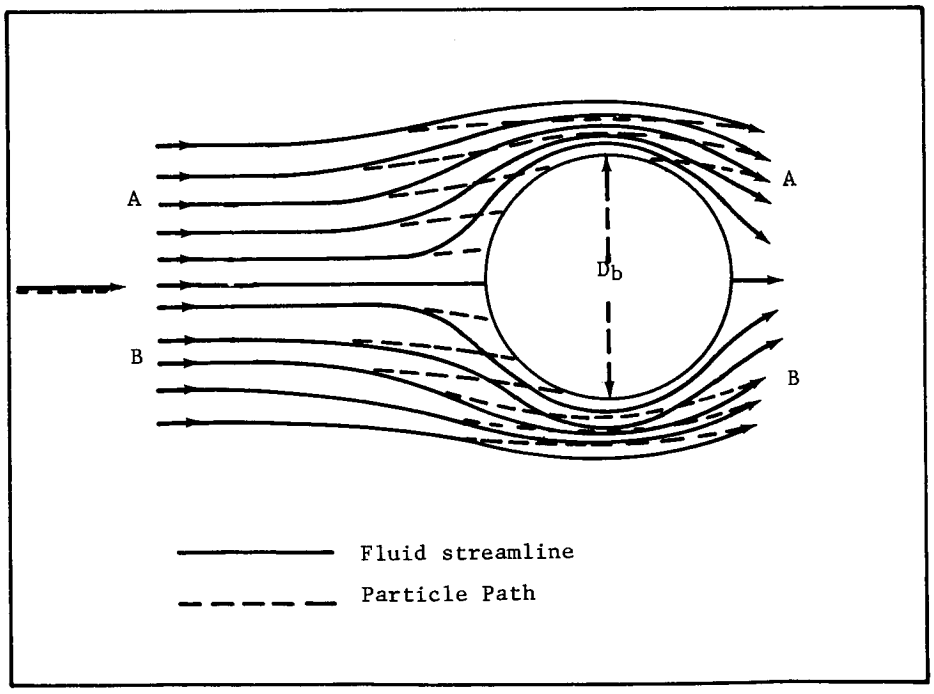
where N is the total number of collector stages in the cathode space. This can be shown to depend upon collection per pass (X_{in}/X_{out}) and the contact efficiency ($N = \frac{1}{\gamma_t A_f} \ln X_{in}/X_{out}$). Thus the total current delivered to the collector grid will

depend upon: (1) the fraction collected, (2) the residence time in the regenerator ($(\eta_e - \eta)$ term), and (3) system hydrodynamics (Q, γ_t).

The electrolyte slurry flow in the cathode space controls both the total number of coulombs delivered to the cell and the collection efficiency. While residing in this collector space the catalyst-slurry encounters a series of cylindrical collector wires or obstacles. When the catalyst laden electrolyte impinges on the screen wires, the fluid phase will be deflected around the wire, while the particles will impact on the screen due to their much higher density and hence increased inertia. Of course, the higher the incident velocity, the more effective is the current collection. After impaction, the wires are "cleaned" of discharged particles by subsequent impactions. Figure 3 illustrates the concepts of inertial impaction (4, 5, 6). The collection problem reduces to calculating what fraction of the incident particles in the volume vds actually impinge upon the collector surface. Fortunately, this relationship can be readily derived for cylindrical collector geometry (3, 4, 7) from classical hydrodynamics if one assumes potential flow. In this analysis (Langmuir) the trajectories of individual particles are calculated to determine the target efficiency. The relationships derived from potential flow should also hold if the flow around the collector body is turbulent, since conditions upstream of the obstacle should approach potential flow and these latter conditions dictate the incident particle velocity. However, collector wires should not be so close that they produce appreciable flow distortion.

FIGURE 3

IMPINGEMENT COLLECTION CONCEPT



Therefore, the hydrodynamic analysis of Langmuir and Blodgett* can be used to predict collection efficiency (γ_t). This analysis indicated that collection efficiency could be calculated using two dimensionless groups; K, the dimensionless range parameter and φ, the Stokes Law parameter. Thus,

$$\gamma_t = f(K,\varphi) = f\left(\frac{2\rho_s a^2 v}{9\mu d}, \frac{18\rho_L^2 d v}{\mu \rho_s}\right) \quad \text{or}$$

$$K = \frac{2\rho_s a^2 v}{9\mu d}, \quad \varphi = \frac{18\rho_L d v}{\mu \rho_s},$$

where μ is the electrolyte viscosity and d is the diameter of the wire. For a cylindrical collector wire, the analysis leads to the following equations:

Stokes Law Region $\varphi = o$

$$\gamma_t = 0.466\ (\mathrm{Log}_{10} 8K)^2 \qquad 0.125 \leqslant K < 1.1 \qquad (8)$$

$$\gamma_t = K/(K + \pi/2) \qquad 1.1 \leqslant K \qquad (8a)$$

For Higher Values of φ

$$K_o = \frac{\lambda}{\lambda_s}\left(K - \frac{1}{8}\right) + \frac{1}{8}$$

$$\gamma_t = 0.466\ (\mathrm{Log}_{10} 8K_o)^2 \qquad 0.125 \leqslant K_o < 1.1 \qquad (9)$$

$$\gamma_t = K_o/(K_o + He) \qquad 1.1 < K \qquad (9a)$$

where

$$He = \frac{\pi}{2} \text{ for } \gamma_t \leqslant 0.5 \qquad (9b)$$

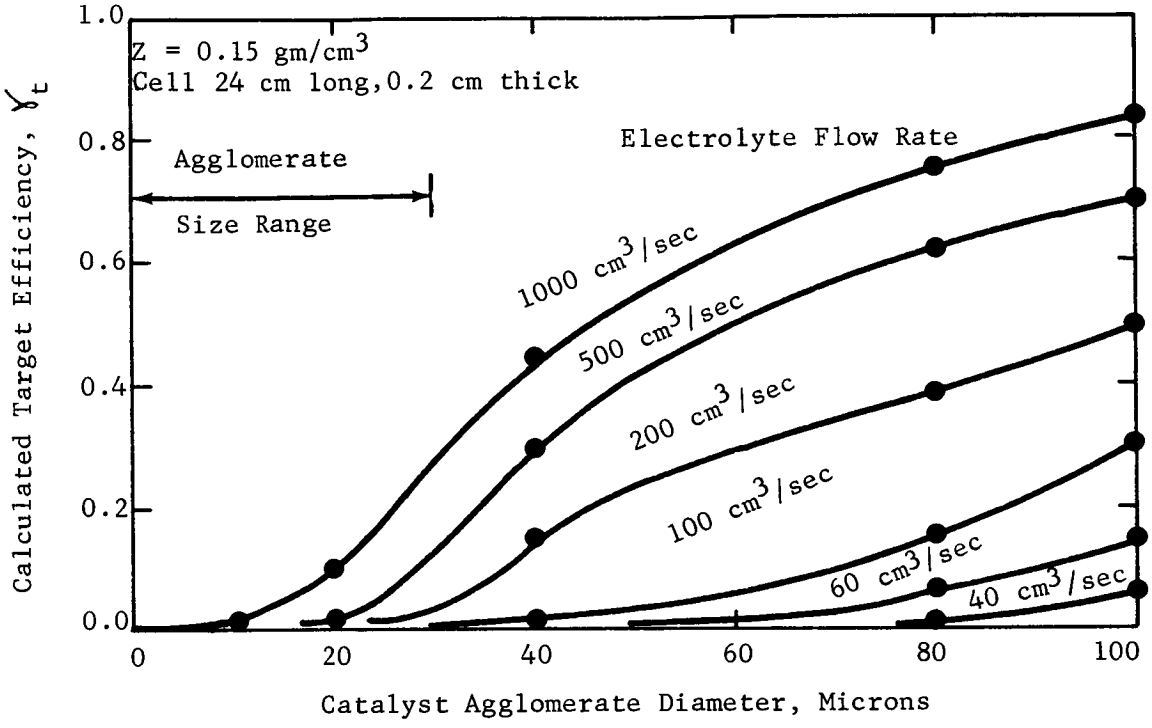
$$He = 1 + 0.57\ (2C_D a \rho\ v_p/\mu) - 0.73 \times 10^{-4}\ (2a\rho v_L/\mu)^{1.38} \qquad (9c)$$

where C_D is the drag coefficient. Detailed curves of target efficiency may be found in reference (5). Fortunately, the explicit form of the solution can be used in this analysis, since φ ranges from 0 to 0.05, where Stokes Law applies. Figure 4 is a plot of calculated target efficiencies as a function of electrolyte flow rate and catalyst particle diameters. Additional target efficiency figures can be found in Appendix III (5, 6, 7). Since flow rates in excess of 200 cm^3/sec are not practical in real collector configurations, and normal platinum agglomerates are smaller than 30 microns (even in 50% KOH), it is evident that we are limited to very low target efficiencies.

* Confirmed by experimental studies.

FIGURE 4

EFFECT OF ELECTROLYTE FLOW ON CONTACT EFFICIENCY



The mechanical slurry discussed in the next section (III) yields φ values ranging from 0 to 10, again allowing use of Stokes law approximation. However, the radial velocity is significantly higher and practical contact efficiencies are obtainable.

Part b - Regenerator-Absorber System

The regenerator-abosrber unit associated with the moving bed cathode performs two functions. It provides the required oxygen transport volume and gives sufficient hold-up time to allow the catalyst particles to return to their equilibrium polarization (η). Thus, the minimum volume system depends primarily on regeneration time. The current generated in this process serves only to charge the double layer capacitance of the particle. As the oxidation reaction proceeds, the particle polarization decreases, following the Tafel equation. The change in polarization is simply,

$$\frac{d\eta}{d\theta} = -\frac{i}{c}, \tag{10}$$

where θ is time (sec), i is the current density, amps/gm catalyst, and C is the capacitance in Farads/gm of catalyst. Substituting the Tafel equation,

$$\frac{i}{i_L - i} = \frac{i_o}{i_L} \exp \eta/s, \tag{11}$$

$$i = \frac{i_o \exp \eta/s}{(1 + i_o/i_L (\exp \eta/s))} \tag{11a}$$

(equation 11a) into equation 10 yields

$$e^{-\eta/s} d\eta + \frac{i_o}{i_L} d\eta = -\frac{i_o}{c} d\theta \tag{12}$$

where i_L is the diffusion limit (amps/gm of catalyst). Integration between η_e (collector polarization) and η (particle equilibrium polarization) from time 0 to θ_r yields the desired equation for the minimum regenerator residence time θ_r, assuming of course that gas film diffusion is not controlling.

$$\theta_r = \frac{s_c}{i_o} \left[\exp\left(-\frac{\eta}{s}\right) - \exp\left(-\frac{\eta_e}{s}\right)\right] - \frac{c}{i_L} (\eta - \eta_e) \tag{13}$$

As $(\eta - \eta_e)$ gets small, the second term in Equation 13 becomes unimportant so that in most cases:

$$\theta_r = \frac{s_c}{i_o} \left[\exp\left(-\frac{\eta}{s}\right) - \exp\left(-\frac{\eta_e}{s}\right)\right] \tag{13a}$$

The minimum volume (U_s) in the regenerator occupied by the catalyst slurry is $U_s = Q\theta_r \gamma_t$, while the minimum regenerator volume (and hence, weight) is U_s $(1 + 0.08\ A_R\ I/Q)$, where A_r is the ratio of actual to stoichiometer air rates.

Part c - Application to Systems Evaluation

Using the model developed in part a and b, it is now possible to evaluate the overall systems concept. Two alternate evaluation procedures are possible. Equation 13 or 13a could be used to develop a mathematical relationship for $(\eta - \eta)_c$ for use in Equation 2* or alternately, η, η_e could be selected and the regenerator residence time calculated using Equations 13 or 13a. In view of the potential target efficiency problems discussed in part a, the latter route was selected for the initial analysis in order to determine if flow conditions could be established (independent of regenerator-absorber weight considerations) which could yield usable target efficiencies. This approach was justified, since practical regenerator configurations should not introduce significant power losses, and this unit was not the performance limiting element. The equations used to evaluate the parasitic power requirements of this system are summarized in Appendix II-1.

Analysis of the current collection system was the prime objective of our initial computer analysis. Details of this analysis are summarized in Appendix II-1 and II-3, and the selected cell design parameters (corresponding to a 9" x 5-3/4" cell) are listed in Table 1. An operating temperature of 100°C was assumed, since experimental data on capacitance and viscosity were available at this temperature. Furthermore, at this temperature, system performance would be expected to be maximized.

TABLE 1

PARAMETERS OF MOVING BED SYSTEM

Cell Parameters	
Height: 14 cm Cathode Chamber Thickness: 0.20 cm Grid Sizes: 20 and 50 mesh Target Efficiency (Assumed) 0.05 to 1.0	Width: 24 cm Matrix Thickness: 0.05 cm Electrolyte Flow: 10-300 cm^3/sec Cathode Catalyst Loading: 0.1-0.4 gm/cm^3
Electrolyte	
50% KOH Matrix Resistivity(1) 0.15 ohm - cm^2	Temperature: 100°C Electrolyte Conductivity 0.278 ohm^{-1} cm^{-1}
(1) Matrices reported with values as low as 0.06 are possible. However, above value is typical.	

Analysis of this system by computer indicates that target efficiency critically determines cell performance. This is illustrated in Figures 5 and 6 for a catalyst loading of 0.1 gm/cm^3. Note that the maximum power density decreases from

*Using approach number one, Equation 7 could be written as:

$$I = QzX_{in}sc \left[1-\exp -A_f \gamma_t N\right] \ln \left[1 + \frac{1}{s}\left[\frac{i_o \theta_r}{c} + \frac{i_o}{i_L}(\eta - \eta_e)\right] \exp \frac{\eta_e}{s}\right] \qquad (7b)$$

For development of this equation see Section III.

Figure 5

Effect of Target Efficiency on Cell Performance

(1/3 Ft^2 Cell)

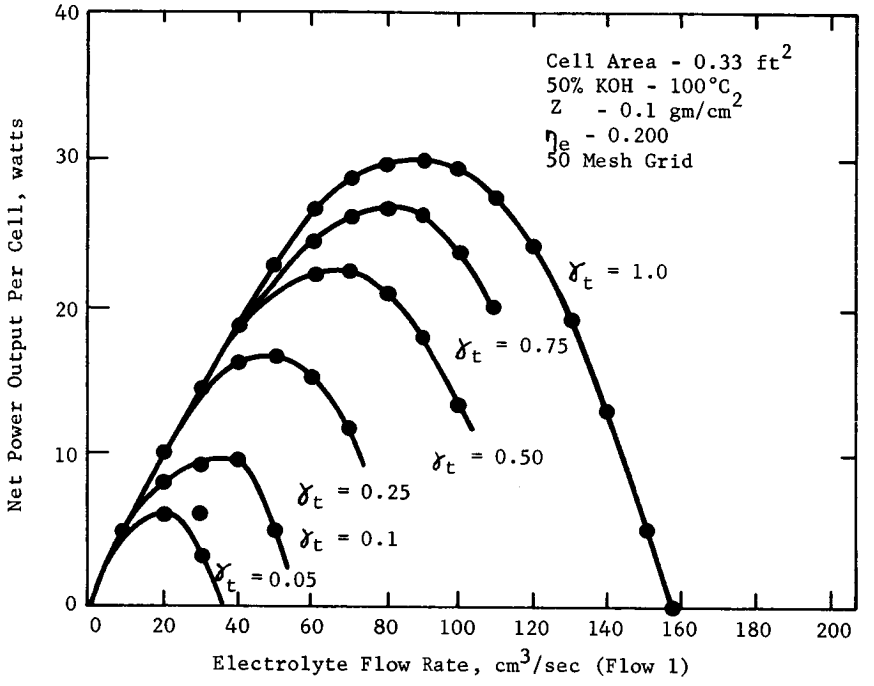
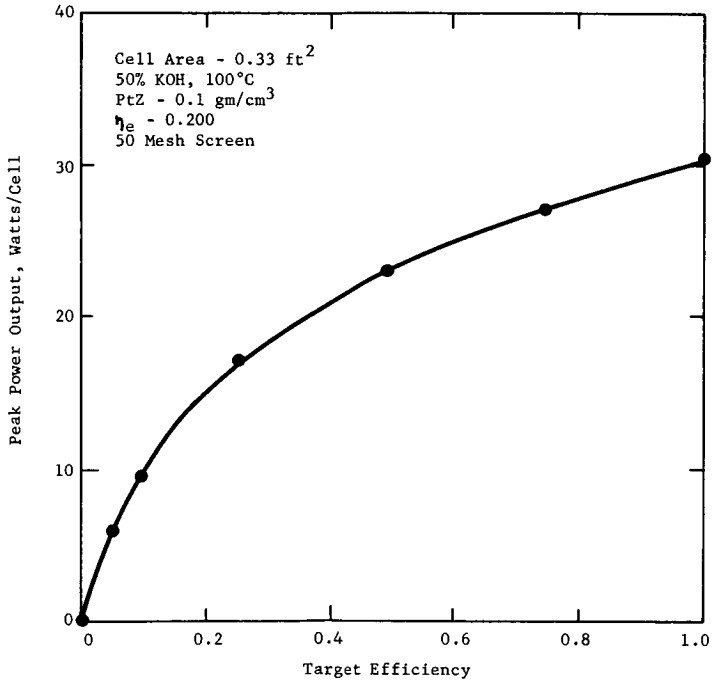


Figure 6

Effect of Target Efficiency on Peak Power

(One-Third Ft^2 Cell)



90 watts/ft^2 at γ_t = 1 to 30 w/ft^2 at γ_t = 0.1 and 18 w/ft^2 at γ_t = 0.05. Even at the maximum target efficiency, the power density obtained with this (0.1 gm Pt/cm^3) system was well below what is currently available in conventional H_2-O_2 fuel cells. Increasing platinum loading (Figure 7) to 0.2 and 0.4 gms/cm^3 does improve power capability somewhat. However, at 0.9 volts/cell the effect is seen to be quite small (144 vs 90). Allowing the voltage to drop to 0.85 volts per cell increases the power density to 186 w/ft^2.

Figure 7

Performance of Moving Bed Cell

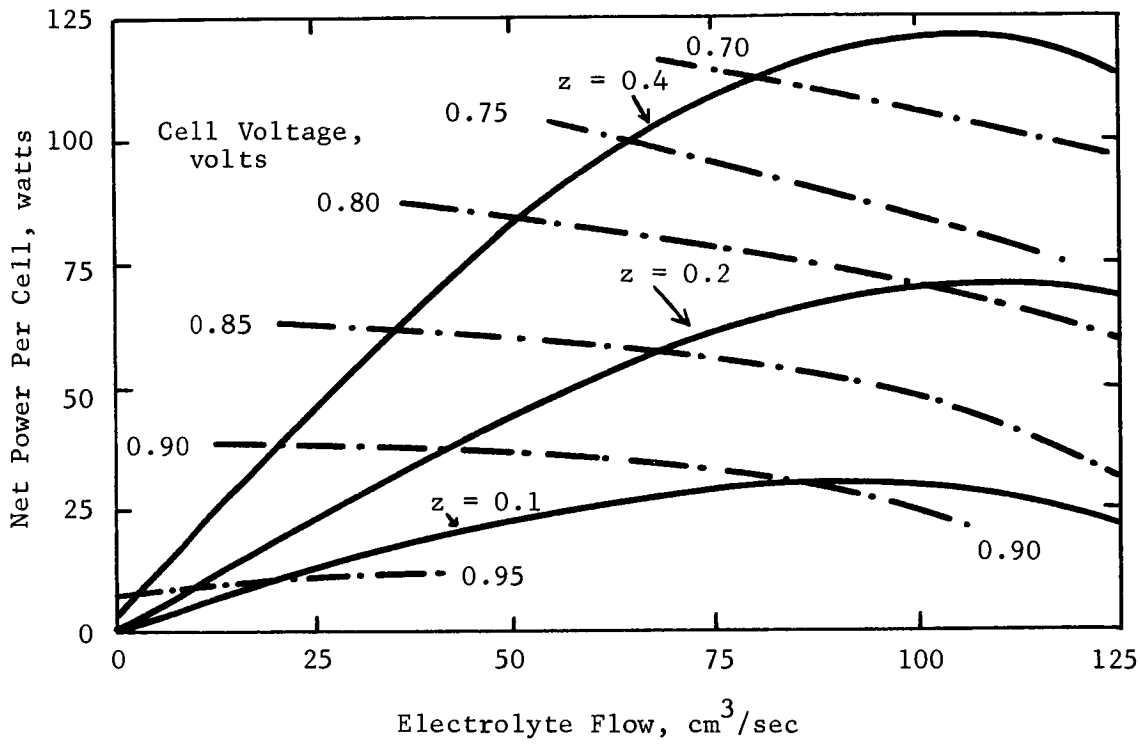


TABLE 2

COMPARISON OF POWER DENSITIES OF
MOVING BED AND CONVENTIONAL CATHODES

	Power Density At Indicated Cell Voltage, watts/ft^2	
	0.9v.	0.85v.
Moving Bed (γ_t = 1.0)	114	186
Cyanamid AB40 Cathode(1) and Other 50 mg/cm^2 Sintered Platinum-Teflon Electrodes	180	425
Esso Proprietary Structure 50 mg Pt/cm^2	450	640

(1) AB40 tests with special matrix, all others based on matrix resistivity at 0.15 ohm cm^2.

A comparison of these power densities with those available with present generation interface-maintaining electrodes (Table 2) indicates that even under the best conditions, the moving bed cathode is poorer than current cathode structures. Furthermore, if the real contact efficiency data (Figure 4 and Appendix II-5, 6, 7) are included, the system will turn out to be a net power consumer, since catalyst agglomerate size rarely exceeds 30 microns. Positive power output is not obtained until agglomerate sizes reach 80-100 microns (See Table 3). Consequently, the moving bed cathode concept was abandoned in favor of an analysis of a (mechanical) slurry system.

TABLE 3

CORRECTED POWER OUTPUT
OF MOVING BED CATHODE CELL

(Corrected for Target Efficiency)
(20 Mesh Screen)

Catalyst Loading gm/cm^3	Gross Power, watts	Net Power Output at Indicated Agglomerate Diameter, watts			
		40 μ	60 μ	80 μ	100 μ
$Q = 100\ cm^3/sec$					
0.1	148	0	48	63	72
0.2	264	0	0	165	189
0.4	415	0	0	123	291
$Q = 200\ cm^3/sec$					
0.1	291	0	0	54	102
0.2	528	0	0	72	252
0.4	894	0	0	477	486

SECTION III

SLURRY CATHODE CONCEPTUAL DESIGN (MECHANICAL AGITATOR)

The moving bed fuel cell conceptual design failed to provide the anticipated power density improvements because the slurry flow rates required to provide high currents and useful target efficiencies introduced excessive parasitic power losses even at unrealistically high catalyst agglomerate sizes. Furthermore, moving the catalyst into a separate regenerator space introduced a significant "dead time" which further limited performance, increased catalyst requirements, and increased system weight. The slurry cathode conceptual design circumvents these problems by providing a high (radial) velocity for collector impaction and charge transfer, while retaining the catalyst in the cell reaction volume for regeneration. Unfortunately, this system has one disadvantage in that complete decoupling of anode and cathode is not possible. However, substantial geometric decoupling is obtained.

The mechanical slurry system shown schematically in Figure 8 resembles the moving bed cathode in that it also uses a suspended catalyst as the "oxygen transfer agent". However, it differs in that the catalyst particles never leave the cell proper since regeneration occurs in the bulk electrolyte. Thus, the slurried catalyst reacts with dissolved oxygen in the electrolyte to charge the catalyst particle. The charged slurry is picked up by the impeller and "pumped" against the collector screen where it is discharged and returned to the bulk slurry for regeneration. This configuration reduces the residence time between strikes so that the charge transferred per strike is reduced. However, the number of effective strikes per unit time more than compensates for this. Furthermore, the slurry is not transferred out of the cell proper for regeneration so that multiple strikes are possible. This latter restriction means that oxygen transport in the cell volume must either be adequate or a circulating (catalyst free) electrolyte stream must be provided to transport the required oxygen. Figure 9 illustrates one such system. However, other investigators have indicated that if an oxygen absorber is required it might introduce an excessive weight debit.

Figure 8

Schematic of Slurry Cell

(Gas Injection Type)

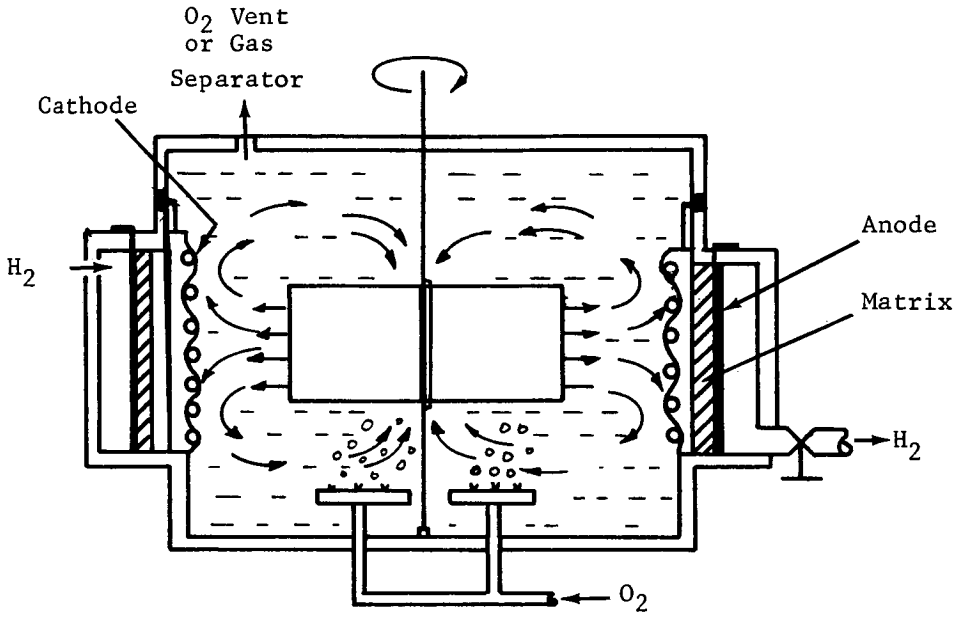
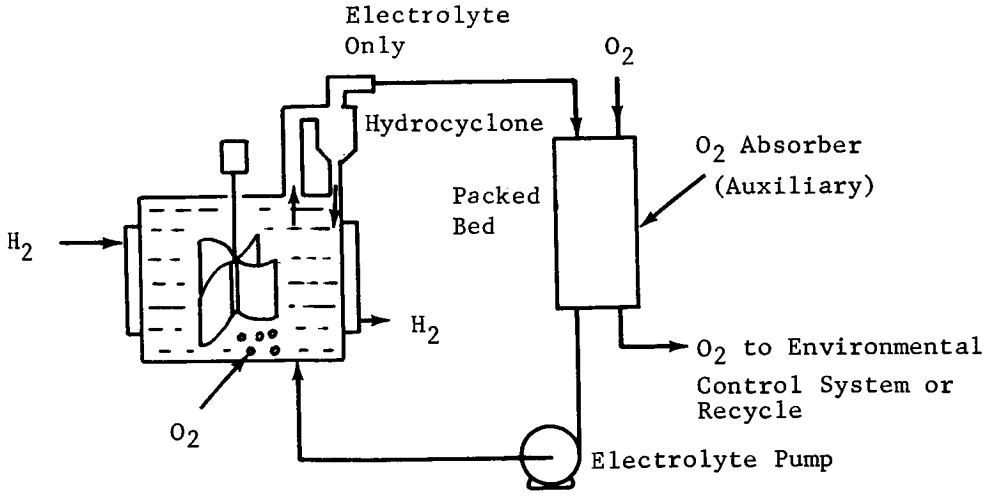


Figure 9

Schematic of Slurry Electrode System



(1) Only electrolyte circulated to absorber.

(2) Auxiliary absorber may not be required.

Part a - Current Collector Model

The (mechanical) slurry electrode system is electrochemically identical to that of the moving bed system. Only the hydrodynamics are altered to favor impaction and improve target efficiency. Thus, the catalyst particle contacts the collector screen and discharges to a polarization η_e. It then circulates in the slurry for a time θ_r, recharging the double layer by reaction with dissolved oxygen. It can be shown that Equation 13 (Section II) defines the relationship between catalyst potential and residence time for both the moving bed and slurry cathode systems. Thus, Equation 13 can be used to calculate the coulombs available at the collector screen $((\eta_e-\eta)c)$.

Re-arrangement of Equation 13 to obtain the "free" catalyst particle polarization yields

$$\eta = s \ln\left[\left(\frac{i_o\theta_r}{sc}\right)\exp\left(\frac{\eta_e}{s}\right) + \left(\frac{i_o\theta_r}{i_L s}(\eta-\eta_e)\right)\exp\left(\frac{\eta_e}{s}\right) - 1\right] - s \ln \exp\left(\frac{-\eta_e}{s}\right) \qquad (14)$$

Since $+\eta_e = -s \ln e^{-\eta_e/s}$*, the coulombs per gram of catalyst impinging on the collector becomes

$$(\eta_e-\eta)c\left(\frac{\text{Coulb.}}{\text{gm cat}}\right) = sc \ln\left[1 + \left(\frac{\theta_r i_o}{sc}\right)\exp\left(\frac{\eta_e}{s}\right) + \left(\frac{(\eta-\eta_e)i_o}{s\ i_L}\right)\exp\left(\frac{\eta_e}{s}\right)\right] \qquad (15)$$

Neglecting the tangental velocity component of the impeller velocity (valid for turbine bladed impellers with 90° blades) the current collected by the collector grid can be shown to be

$$I = (Q_r\gamma_t A_s z)(sc \ln\left[1 + \left(\frac{\theta_r i_o}{sc}\right)\exp\left(\frac{\eta_e}{s}\right) + \left(\frac{(\eta-\eta_e)i_o}{s i_L}\right)\exp\left(\frac{\eta_e}{s}\right)\right] \qquad (16)$$

where Q_r** is the radial pumping capacity of the impeller, γ_t is the target efficiency, and A_s is the ratio of the collector cross-sectional area to the total cross-section for flow. In the first phase of this analysis, it was assumed that diffusion was not limiting so that the last term in Equation 16 $(i_o(\eta-\eta_e)/si_L \exp(\eta_e/s)$ was neglected. This latter term might have to be included in any final design of the system. The values of s, c, and sc/i_o required for Equation 16 are calculated using the equations in Appendix II-2 and experimental polarization decay measurements. Other values of capacity can also be used with the computer program discussed in Appendix III-1.

---

* $-s \ln \exp\left(\frac{\eta_e}{s}\right) = -s\left(\ln 1 - \ln \exp\left(\frac{\eta_e}{s}\right)\right) = s \ln \exp\left(\frac{\eta_e}{s}\right) = \eta_e$

** For other impellers Q_r should be the vector sum of the radial and tangential pumping rates.

Target efficiencies were again calculated using the Langmuir and Blodgett equations since Stokes law drag coefficients are again applicable (Equations 8 and 8a). The value of K (for use in Equation 8) can be derived from impeller hydrodynamics,

$$K = \frac{2\rho_p r^2 {}_p Q_r}{9\mu d_w \pi Dh\alpha}, \text{ where} \tag{17}$$

d_w is the collector wire diameter, h is the impeller height and α corrects for the increase in disturbed volume with increased cell diameter (function of the ratio of impeller to cell diameter empirically derived from a hydrodynamically similar system page 195 reference (9)). For a turbine bladed impeller with 90° blades the radial pumping capacity is $Q_r = N$ (rps) h $(\pi d)^2 (cm^3/sec)$ so that Equation 17 becomes

$$K = 0.222 \left(\frac{\rho_p r_p^2}{\mu d_w}\right) \pi \frac{Nd^2}{D\alpha} \tag{17a}$$

Thus, the target efficiency can be directly calculated from impeller and cell dimensions.

The final term required to determine the current output of the cell is the residence time which is the ratio of the total catalyst content of the system to that discharged per unit time. Thus, if the total catalyst charge is $\pi D^2 Hz/4$* and the catalyst discharge rate ($vs\gamma_t z$) is $\pi^2 Nd^2 h\gamma_t A_s$ (gms/sec), the residence time can be shown to be

$$\theta_r = \left(\frac{1}{\pi\gamma_t A_s}\right) \left(\frac{D}{2d}\right)^2 \frac{H}{Nh} \tag{18}$$

Part b - Power Calculation

The gross power output of the cell can be determined using the equations developed in the previous section since the cell voltage will depend upon η_e and the resistance of the cell separator matrix (R = 0.15 ohm-cm^2). Thus, the gross power is simply

$$P_g = I(E_o - (\eta_e + \eta_a + \frac{I}{\pi Dh} R)) \tag{19}$$

where η_a is the anode polarization. The parasitic power required to turn the impeller can be calculated using equation 20.

$$P_L = 10^{-7} N_p \rho_L N^3 d^5 \quad \text{(watts)} \tag{20}$$

where N_p is the power number. The power number used in equation 20 was obtained from

* H is the cell height.

a standard curve for turbine bladed impellers (page 74, reference 10) assuming that the perturbation in power number for impeller diameter to cell diameter ratios of 0.9 to 0.95 could be neglected and the slurry behaved as a Newtonian liquid having a viscosity given by Equation II-9. These two assumptions are self-compensating at low and intermediate Reynolds numbers, while yielding somewhat pessimistic parasitic power losses at very high Reynolds numbers.

Furthermore, it is interesting to note that the gross power output is zero until a critical pumping rate is reached. Above this critical value the gross power increases approximately as $N d^2$ while the parasitic power increases as $N^3 d^5$. Consequently, the slurry cathode cell will have a narrow operating range with a sharp cut-off at moderate impeller speeds.

Part c - Computer Analysis

The computer program listed in Appendix III-1 was designed to investigate the effect of cell geometry (height and diameter), impeller geometry and impeller speed on slurry cathode performance. Preliminary calculations assuming various numerical values for γ_t indicated that increasing cell height above six inches would not significantly improve performance. The cell diameter should be set as small as engineering considerations would allow (two inches). Impeller design practice sets the maximum impeller height at 2/3 the cell height, while impaction considerations indicated that the ratio of impeller to cell diameter should approach unity. Using these findings, a more exact solution, including the hydrodynamics of impaction, was obtained for a series of cell designs to determine the performance and range of operability of the slurry cathode fuel cell conceptual design. The parameters selected are summarized in Table 4.

Table 4

Design Parameters of
Slurry Cathode Fuel Cell

Cell Height: 15.25 cm
Impeller Height: 10.0 cm
Impeller Diameter: 5.08 to 15.25 cm
Radial Clearance: 0.18 cm (70 mils)
Agglomerate Diameter: 0.0001, 0.001, 0.002 cm
Matrix Resistance: 0.15 ohm-cm^2
Catalyst Loading: 0.1 to 0.4 gm/cm^3
Impeller Speed: 0-30 rps
Collector Polarization: 0.05 to 0.30

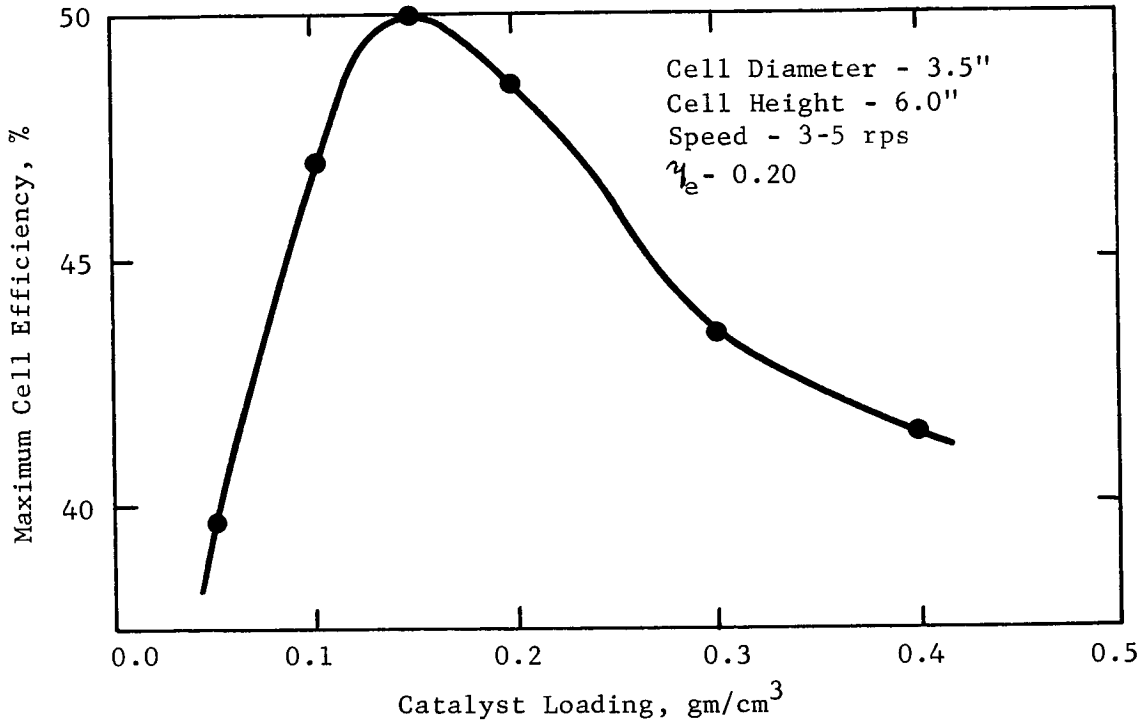
The calculated results are tabulated in Appendix III-2. The effect of impeller diameter on cell voltage-power characteristics are summarized in Appendix III-3.

These calculations indicated that the power output was zero for agglomerate sizes less than 20μ, despite the fact that K values were significantly higher than in the moving bed system. Furthermore, for 20μ particles the low speed cut-off was found to be about 3 rps. Subsequent calculations were based upon 20μ agglomerates.

The effect of catalyst loading on overall system efficiency was examined next using a collector polarization of 0.2 volts. This latter voltage was selected because initial studies indicated that it was close to the potential for maximum overall efficiency. As indicated in Figure 10, the optimum efficiency (50%) was obtained with a catalyst loading of 0.15 gm/cm.^{3} However, the response is quite flat between 0.1 and 0.2 gm/cm^3 so that a value of 0.1 gm/cm^3 was used in subsequent calculations since (1) a 50% increase in platinum loading would not be justified to attain only a 3% improvement and (2) experimental values used are not good enough to warrant discrimination between 47 and 50%.

Figure 10

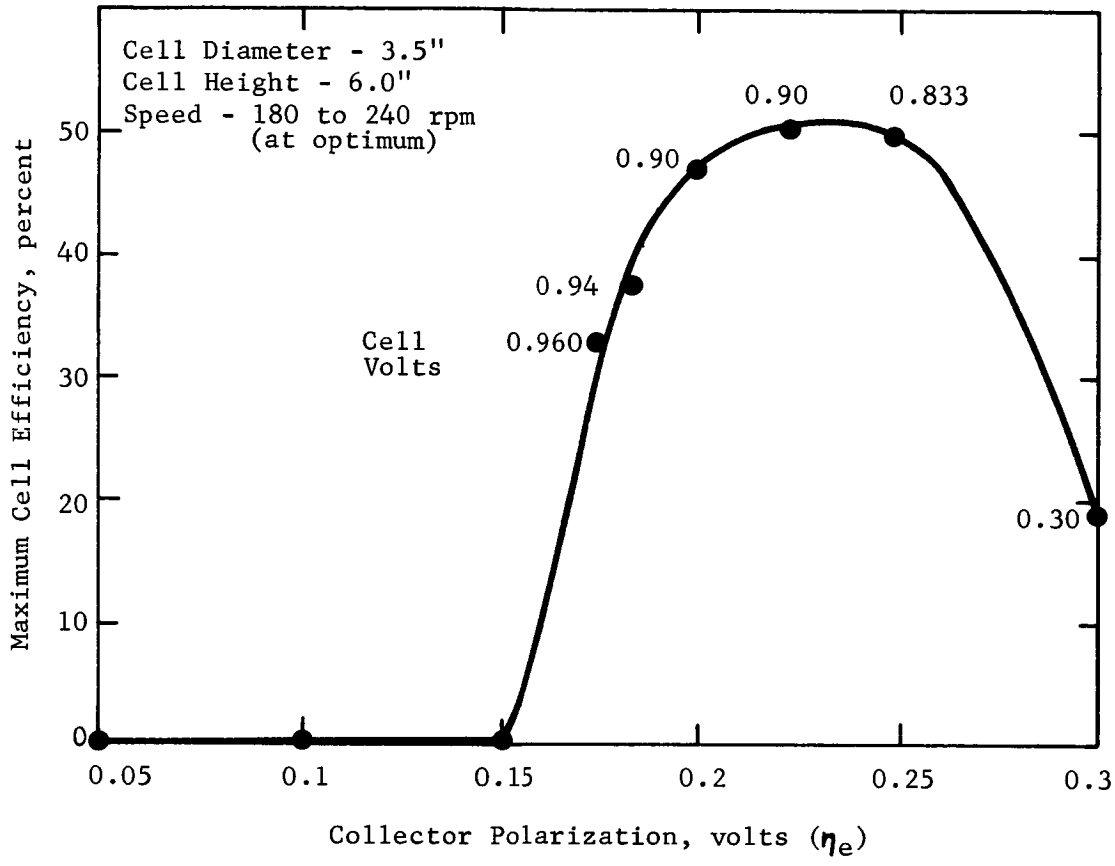
Effect of Catalyst Loading On Cell Efficiency



Next, the effect of collector polarization on system efficiency was examined. As discussed earlier, the idea behind the slurry electrode concept was its potential for operation near theoretical open circuit. In principle, this would allow operation with collector polarizations of 50 or 100 mv and should result in improved system efficiency. As indicated in Figure 11, this was found to be incorrect since our calculations indicate no net power capability at collector polarizations below 150 mv from theoretical oxygen. Furthermore, the maximum overall efficiency was found to occur at a collector polarization of 225 mv. Unfortunately, the maximum efficiency was only 50% or 53% if 0.15 gm/cm^2 is used.

Figure 11

Effect of Collector Polarization on Overall System Efficiency



Present generation interface-maintaining electrodes can attain 60% efficiency on this same basis, and experimental electrodes could yield 65% efficiency. This poor performance stems directly from the poor performance at low polarizations.

Furthermore, as indicated in Table 5, the slurry system has no weight advantage over current systems. Even at the smallest practical diameter, the specific power (lb/kw) is no better than conventional systems. Total packages are currently being built at 15-20 lb/kw level. Furthermore, it is quite likely that auxiliary mass transport equipment might be required. If this is indeed the case, the slurry cell would be significantly poorer than conventional interface-maintaining electrodes.

In view of these findings, the slurry system does not appear to be a promising route to improved H_2-O_2 fuel cell performance.

Table 5

Power Density of Slurry
Cathode - Fuel Cells

Cell Diameter, Inches	Power Output, watts/cell	Specific Power lb/kw	System* Efficiency	No. Cells
2.10	50	24.2	51	20
2.75	66	29.5	50	15
3.10	80	31.0	48	13
3.5	90	35.0	47	11
5.1	90	48	45.5	11
5.1	115	57.5	40.5	9
6.1	115	83.0	40.0	9

* Includes parasitic losses in the cell but not power conditioning or heat and water balance power requirements.

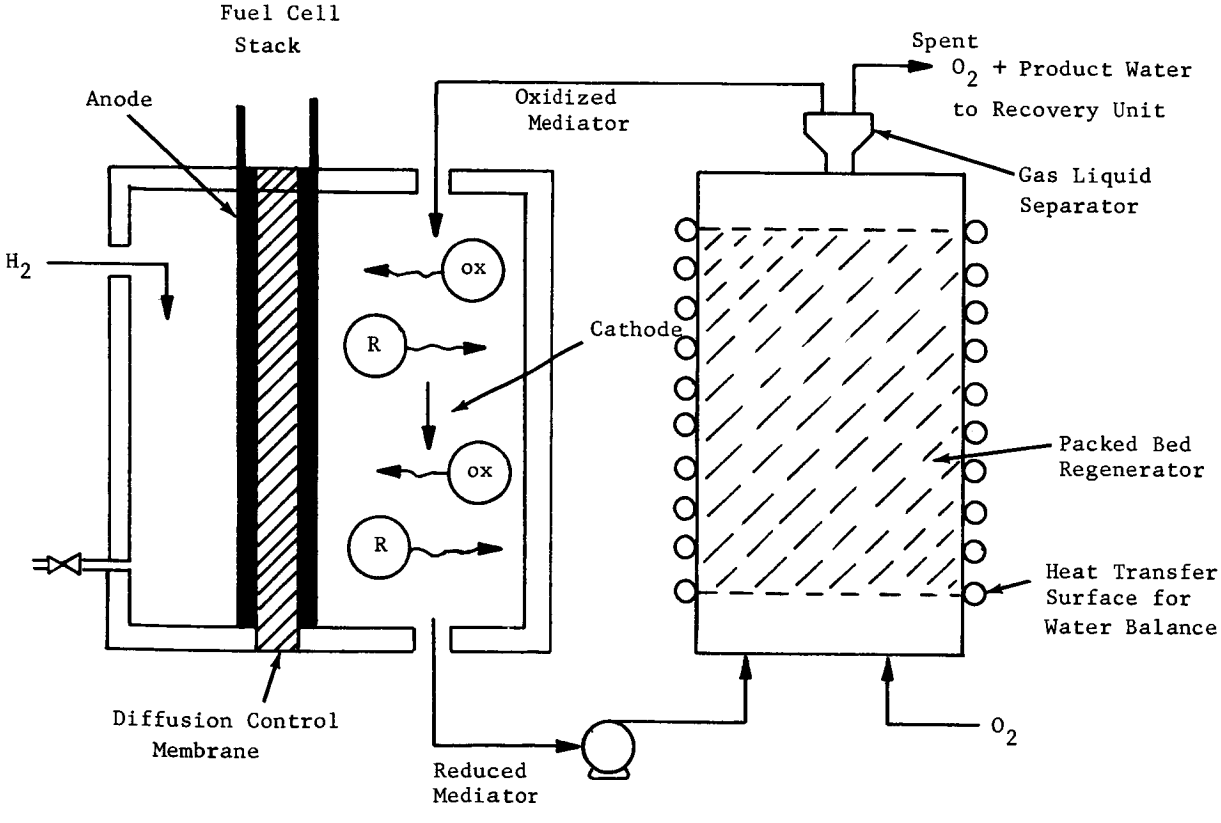
SECTION IV

MEDIATOR FUEL CELL

The mediator (cathode) fuel cell concept provides another possible solution to the anode-cathode imbalance problem encountered in conventional H_2-O_2 systems. The concept involves the use of a soluble organic redox couple cathode where i_o is comparable to or higher than interface maintaining hydrogen anodes. The couple selected, 1,2-dicyano-benzoquinone (11), behaves reversibly, is readily regenerated with oxygen or air, and both the oxidized and reduced species remain dissolved in the electrolyte. The cathode system illustrated in Figure 12 is analogeous to soluble fuel fuel cell anode (such as methanol) in that the oxygen carrier is dissolved in the flowing electrolyte stream. Thus, oxidation of the reduced couple is accomplished external to the cathode chamber.

Figure 12

Schematic Mediator Fuel Cell

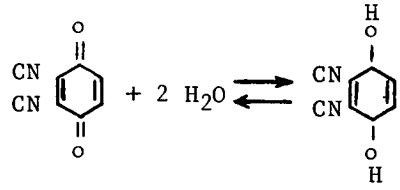


Several cathode configurations were considered for this system concept, including porous planar, packed bed, and internal regenerator (packed bed) cathode. The planar configuration was selected for this analysis because the surface area enhancement obtained with conventional conductive packings is only 60%* and this was felt to be insufficient to compensate for the increased ohmic and parasitic pumping losses due to the packing. However, should improved packing become available, this could significantly reduce system weight through reductions in electrolyte flow rate, which might reduce scrubber system weight. The internal regenerator cathode was not examined because the small internal cell volume available would not significantly affect scrubber weight or cathode polarization. As in the case of the soluble fuel fuel cell, a diffusion control membrane is required to prevent transport of the redox couple to the anode while still allowing good ionic conduction. Some experimental membranes appear to meet this requirement. For example, an experimental membrane will not pass a dye such as methylene blue while still retaining good ionic conduction. It is quite probable that this membrane would also retard dicyano-benzoquinone.

Thus, the development of a mathematical model for this mediator fuel cell concept will require independent mass transport analyses of the cathode space and the scrubber-regenerator. As in the previous cases, the cathode space was examined first to determine if adequate current capability was available prior to analysis of the scrubber-regenerator system.

Part a - Cathode Chamber Analysis -
<u>Planar Electrode Structure</u>

The mediator fuel cell cathode is based upon a reversible redox couple with an E_o (0.971) near theoretical oxygen. It differs from the conventional cathode since the "chemical" oxidation step takes place externally to the cathode chamber. A circulating electrolyte flowing at velocity v carries the oxidized couple (concentration C_{ox}) into the cathode chamber where it is electrochemically reduced at the catalytic electrode in accordance with the half cell reaction.



(21)

For this reversible reaction, the theoretical open circuit potential is given by the Nernst equation,

$$E_{oc} = E_o + \frac{RT}{2F} \ln \frac{[C_{ox}]_o}{[C_{Red}]_o} \qquad (22)$$

where $[C_{ox}]_o$, and $[C_{red}]_o$ represents the concentration of the oxidized and reduced species (M/cm^3) either in the bulk solution, stagnant or well-stirred cases, or at the edge of the concentration boundary layer. Under load, the concentrations at the electrode surface ($-\delta$ Figure 13) are altered so that the potential becomes

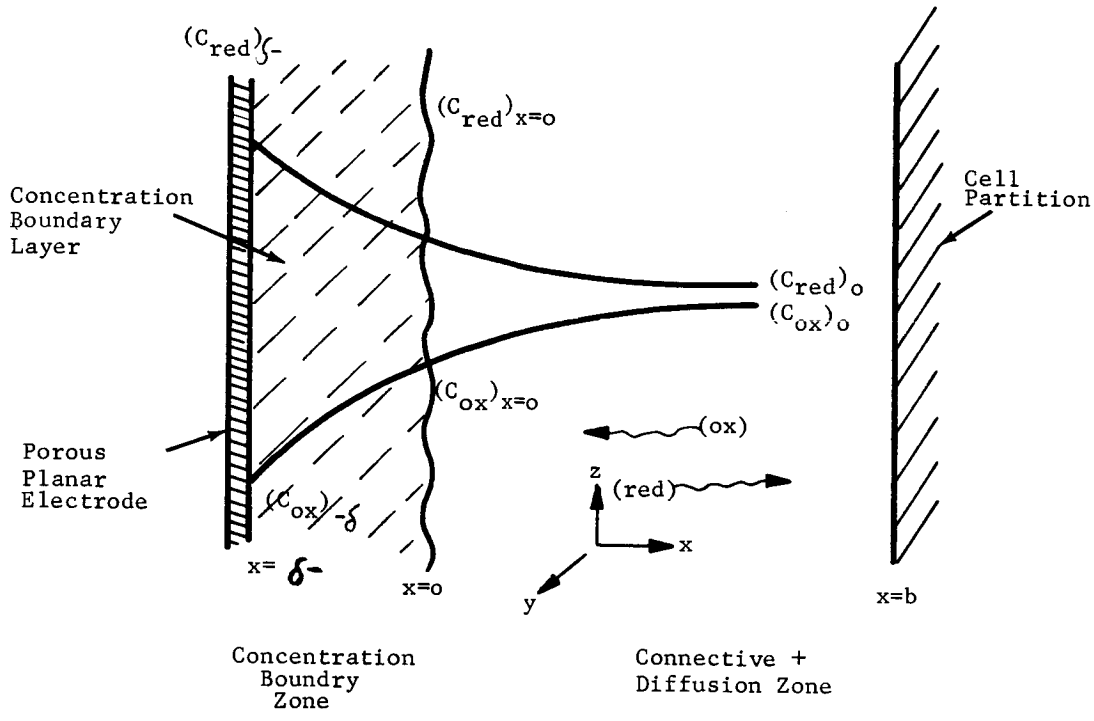
$$E_i = E_o + \frac{RT}{2F} \ln \frac{[C_{ox}]_{\delta-}}{[C_{Red}]_{\delta-}} \qquad (23)$$

* Area factor ranges from 4.6 to 8 cm^2/cm^3 of packed volume for commercial mm size packing.

provided we neglect the effect of electrode porosity. This latter assumption is valid for fast reversible electrode processes.

Figure 13

Concentration Profiles Oxidized and Reduced Forms



The concentration polarization η_c can then be determined using equations (22) and (23). Thus, the cathode polarization, as indicated by mediator theory, can be shown to be

$$\eta_c = E_{oc} - E_i = \frac{RT}{2F} \ln\left[\frac{[C_{ox}]_{x=o} [C_{Red}]_{\delta-}}{[C_{Red}]_{x=o} [C_{ox}]_{\delta-}}\right] \qquad (24)$$

Therefore, a mass transport analysis of the cathode chamber is required to determine the cell voltage current characteristics. In this analysis the cathode chamber is divided into two zones as illustrated in Figure 13. The bulk of the chamber (x = o to b) is subject to the combined effect of convection and diffusion, while in the region x = o to $-\delta$ only diffusion occurs through the concentration boundry layer. This analysis, summarized in Appendix IV-1, indicates that the cathode concentration polarization is a complex function of velocity given by

$$\eta_c = \frac{RT}{2F} \ln \frac{\left(1 + \frac{I}{2FDM(1-X_o)}\left[0.347\left(\frac{\mu h}{\rho v}\right)^{\frac{1}{2}}\left(\frac{\rho D}{\mu}\right)^{0.333} + 0.667\left(\frac{\pi Dh}{v}\right)^{\frac{1}{2}}\right]\right)}{\left(1 - \frac{I}{2FDMX_o}\left[0.347\left(\frac{\mu h}{\rho v}\right)^{\frac{1}{2}}\left(\frac{\rho D}{\mu}\right)^{0.333} + 0.667\left(\frac{\pi Dh}{v}\right)^{\frac{1}{2}}\right]\right)} \qquad (25)$$

where I is the current density (amps/cm^2), μ is the viscosity (poise), h is the cell height, D is diffusivity, ρ is electrolyte density, M is the mediator concentration (M/cm^3) and X_o at the ratio of the inlet concentration of oxidized mediator to total mediator concentration.

This equation was used to predict the performance characteristics of the mediator fuel cell stack as a function of temperature, mediator concentration, and velocity using the computer program summarized in Appendix IV-2. (Detailed results are in Appendix IV-3). Values of assumed parameters are summarized in Table 6.

Table 6

Parameters of Computer Analysis

Mediator Theoretical Potential, E_o, Volts	0.9712 at 25°C
Temperature Coefficient	-0.70 mv/°C
Flow Rate	10 to 450 cm^3/sec/cell
Cell Size	0.33 ft^2
Diffusivity	10^{-5} cm^2/sec
Matrix Resistance	0.15 ohm cm^2
Mediator Molality	0.5 to 10
Cell Pressure	1 to 9 atm.
Scrubber Pressure	3 to 9 atm.
Scrubber Packing	0.25" Berl Saddle
Temperature	40-95°C

These calculations indicated that cell performance decreased with increasing temperature (Appendix IV-4). Consequently, subsequent analysis assumed an operating temperature of 40°C since previous heat transfer studies on similar systems indicated that this was a reasonable steady state operating point. Next, the effects of electrolyte flow rate and mediator concentration were evaluated. Unfortunately, solubility data on the dicyano-benzoquinone mediator selected were not available in the literature. However, it is safe to assume that its solubility characteristics are similar to the unsubstitute benzoquinone, approximately 0.5 M at 15°C. Thus, the analysis assumes that concentrations of up to one molar can be obtained. Concentration significantly higher than one molar (at 40°C) probably could not be obtained with this mediator. However, evaluations at higher concentrations are discussed in Part b to determine if finding other mediators could significantly affect power density.

Cell analysis indicated that doubling the mediator concentration (0.5 to 1M) was equivalent to a three-fold increase in catholyte flow, without the ensuing parasitic pumping losses, in the region where positive system power is obtained. This is illustrated in Figure 14 which is a plot of limiting current density (ma/cm^2) versus catholyte flow rate (cm^3/sec/cell) for 0.5 and 1.0 molar mediator concentrations. Unfortunately, the cell voltage-current characteristics of the resultant (1 Molar mediator) cell are poorer than that which could be obtained with commercial interface-maintaining electrodes even at the highest catholyte flow rates. This is illustrated in Figure 15.

Figure 14

Effect of Concentration
and Flow Rate on Limiting Current

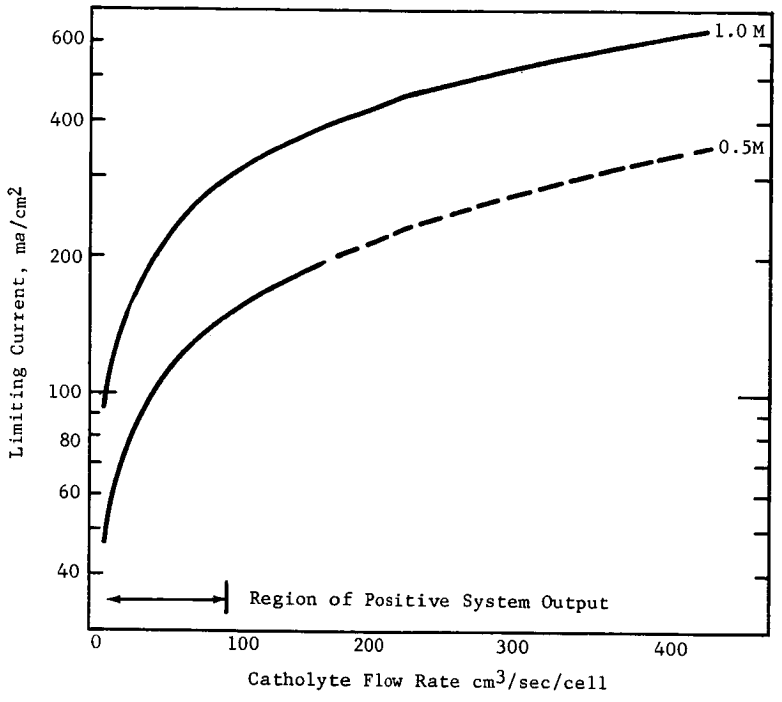
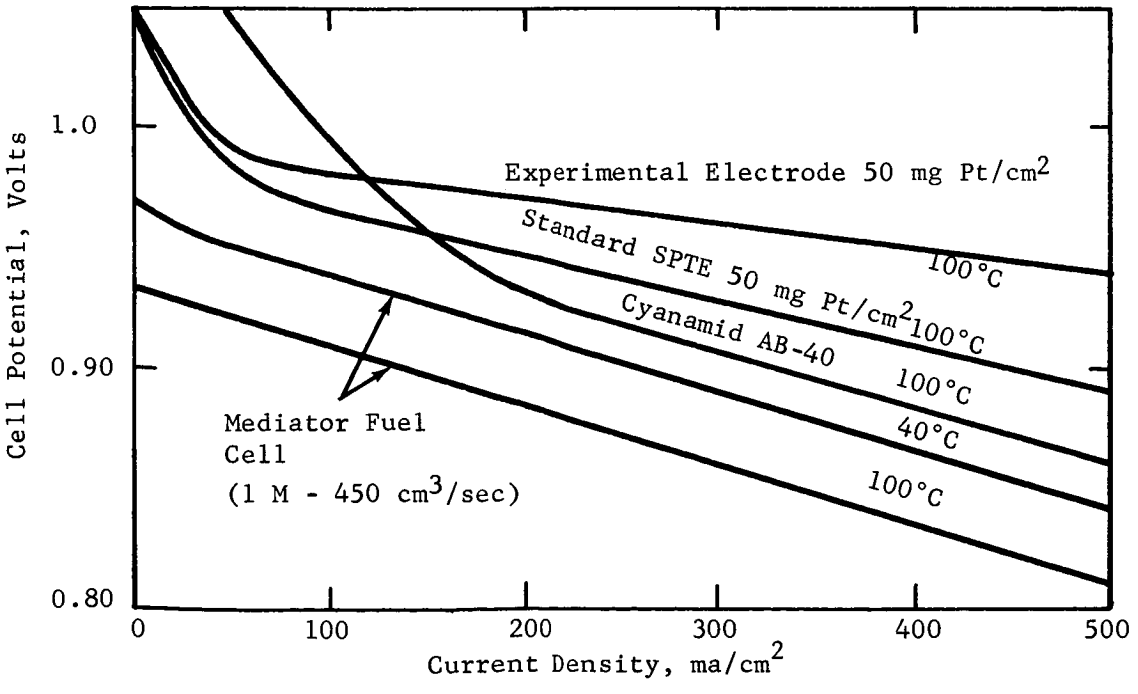


Figure 15

Comparison of H_2-O_2 Fuel Cells



In fact, the single cell performances of two novel experimental cathodes (prepared in our laboratory) were 50 to 100 mv better than the predicted mediator cell performance. Although this mediator fuel cell (based upon dicyano-benzoquinone) system is unsatisfactory, other mediators (redox couples) with higher E_o values could be developed which might result in cell improvements well above conventional electrodes. However, the value of such a development effort would depend upon the specific power (lb/kw) of the overall mediator system. Consequently, evaluation of the design requirements and system weight was initiated to determine if a reasonable specific power value can be obtained if the E_o and solubility of the mediator were increased. The dicyano-benzoquinone mediator was again chosen as the model system. The results obtained can be modified to include the anticipated 50% (maximum) improvement in gross power.

Developing an adequate prediction of the ultimate capability of mediator systems requires a detailed analysis of (1) the scrubber-regenerator system, (2) the fuel cell stack and (3) the parasitic power requirements, excluding power conditioning and coolant flow for water balancing.

Part b - Scrubber Regenerator System

The oxygen absorption process occurring in the regenerator unit presents a somewhat unique problem since the mediator is undergoing a simultaneous reaction with the absorbed oxygen. This reaction is assumed to be instantaneous and "chemically" irreversible (in the presence of oxygen). This latter assumption is justified since the oxidation rate of hydroquinones in base is known to be extremely rapid. This rapid chemical reaction introduces several problems since (1) the concentration distribution of the mediator in the liquid phase influences the overall absorption processes, especially at high (reduced) mediator concentrations relative to oxygen solubility, and (2) the absorption mechanism can change along the length of the absorber. Consequently, the procedure used in the absorber design follows that proposed by Astarita (12).

Starting with the Danckwerts' moving boundary model (Appendix IV-6), the improvement in absorption rate can be calculated (Appendix equation IV-23) assuming the liquid phase diffusivity of the mediator and oxygen are comparable*. The enenhanced absorption rate can then be shown to be a function of the physical absorption rate,

$$\bar{N} = k_L^{\,o}(2b_o + C_i) = kg\ (Py\text{-}HC_i) \qquad (26)$$

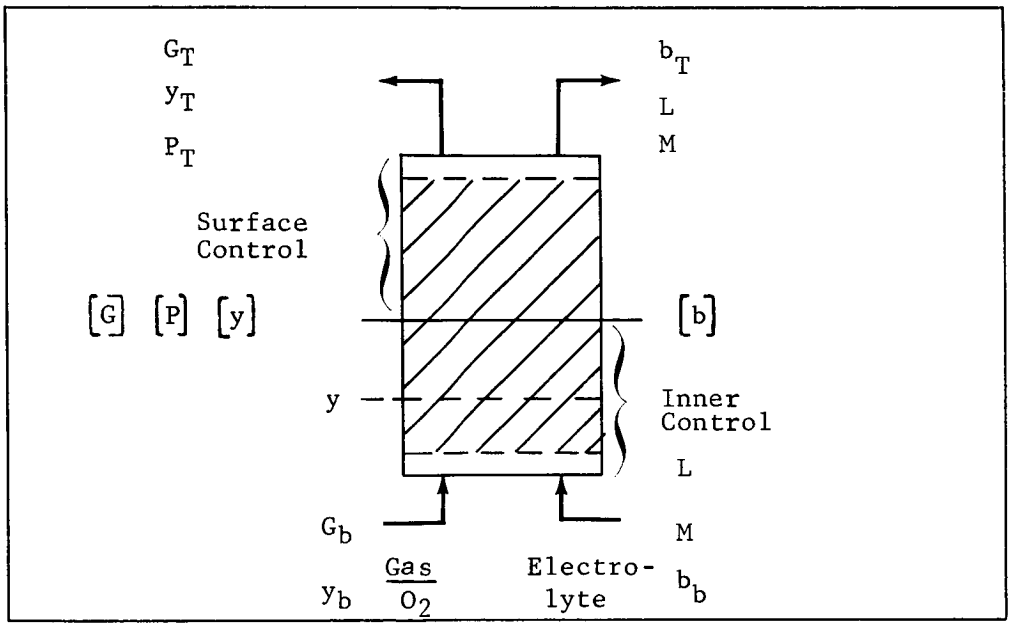
where b is the bulk concentration of reduced mediator and C_i is the interfacial oxygen concentration,
gas phase mass transport coefficient, H is Henry's law constant for O_2 in KOH (atm cm^3/gm mole), y is the mole fraction of O_2 in the gas stream and P is the total pressure at any given point in the column (atm). Examination of Equation 26 indicates that when $kgPy \gg k_L^{o}b_o$, the reaction plane of Danckwert's model is located somewhere within the liquid phase with the inner reaction controlling. If on the other hand, $kgPy < k_L^{o}b_o$, the reaction occurs at the gas-liquid interface and the interface concentration of the mediator drops to zero. This latter condition is termed surface reaction control. Using these conditions, it is possible to determine when the absorption mechanism changes along the column length, thus allowing separate integrations for each section of the absorber.

* This assumption is justified by data on O_2 and hydroquinone.

The co-current flow model shown in Figure 16 was selected because of the relative ease of phase separation under zero "g" conditions. However, both co-current and countercurrent systems were analyzed and the differences in the number of transfer units was found to be slight. The integrated absorber height equations are listed in Table 7. For details see Appendix IV-6. The cross-sectional area of the regenerator-absorber was selected to set the liquid velocity at 60% of the flooding velocity. Parasitic power losses were calculated using the packed bed relationships discussed in Sherwood (13) (Leva, et al). Absorber weight was calculated from packing weights, liquid hold-up and shell weight (assuming 100 mil wall thickness normal). In addition, 10% additional was included for added heat rejection surface for water balance control.

Figure 16

Co-Current Scrubber Design



G - Molal Gas Rate, $\frac{\text{gm-mol}}{\text{sec cm}^2}$

L - Liquid Rate $\frac{\text{cm}^3}{\text{sec cm}^2}$

M - Moles/cm^3

y - Mole Fraction O_2 in Gas

b - Mole Fraction Reduced Mediator

[ ] - Transition Zone Values

Table 7

Scrubber Design Equations

Transition "Reduced" Mediator Mole Fraction:

$$[b] = \frac{\left[\frac{G_b y_b}{2L_M} - b_b\right]}{\left[\frac{Hg}{H_l} - 1\right]}$$

Inner Control Zone:

$$h_i = \left[\frac{H_{OL}}{\frac{L_M}{MH}\frac{P_b}{G_b} + 1}\right] \text{Ln} \frac{\frac{P_b}{G_b}(G_b y_b - 2L_M b_b) + 2\left(L_M \frac{P_b}{G_b} + MH\right) b_b}{\frac{P_b}{G_b}(G_b y_b - 2L_M b_b) + 2\left(L_M \frac{P_b}{G_b} + MH\right) [b]}$$

Surface Control Zone:

$$h_s = H_L \quad \text{Ln} \quad \frac{[b]}{b_T}$$

Absorber Cross-sectional Area:

$$A = 1.29 \times 10^{-2} \left[G'^2 \, a \, \mu^{0.2} / (\epsilon^3 \rho_L \rho_g \varphi)\right]^{\frac{1}{2}} \qquad \frac{cm^2}{cell}$$

G' = Gas Rate gms/sec, L' = liquid rate gm/sec
ϵ = Fraction Free Volume
φ = Function of G'/L' from Flooding Data (13)

Part c - Fuel Cell Stack Design

The fuel cell stack design was based on current state-of-the-art liquid fuel fuel cell designs. The unit cell was assumed to be 9" x 5-3/4" with an active cross-sectional area of about one-third of a square foot. The anode and catholyte chambers were 80 mils thick and the electrolyte matrix thickness was set at 20 mils. All other dimensions were set to duplicate the polypropylene methanol-air unit cell so that weight could be based on actually fabricated components. Other hardware weights (bolts, end plates, etc.) were also based upon current methanol-air fuel cell hardware. Parasitic power calculations were based upon conventional duct pressure drops including entrance and exit losses. However, this parasitic power loss was found to be quite small.

Part d - Computer Simulation

The system described in the previous subsections was simulated using the computer program listed in Appendix IV-7. This computer analysis indicated that at flow rates in excess of 75 to 100 cm^3/sec, the system was a net power consumer. However, as indicated in Figure 17, at flow rates below 50 cm^3/sec, positive values of specific power were obtained even when the fuel cell stack was maintained at ambient (atmospheric) pressure. For this case the best specific power level obtained was 800 lb/kw, much too high for any airborne system. The ambient pressure stack was therefore abandoned in favor of a totally pressurized system. The results of these calculations are summarized in Figure 18. This change resulted in a modest improvement in specific power to 700 lb/kw. However, even pressurization to nine atmospheres failed to make a detectable change in power density (Detailed calculations appear in Appendix IV-8).

Next the effect of changing the solubility and E_o characteristics of the mediator was briefly investigated. These calculations (Table 8) indicate that the best one could reasonably expect from a mediator H_2-O_2 fuel cell would be about 400 to 500 lb/kw, a level which is at least one order of magnitude poorer than conventional H_2-O_2 fuel cell systems. Thus, further development of the mediator fuel cell concept for mobile or space applications is not recommended.

Table 8

Effect of Potential Mediator Improvements

(3 atm Total Pressure)

Mediator Concentration, Molarity	E_o = 0.971v.	E_o = 1.209v.
1	700	564
5	596	480

Figure 17

Power Density Mediator Fuel Cell

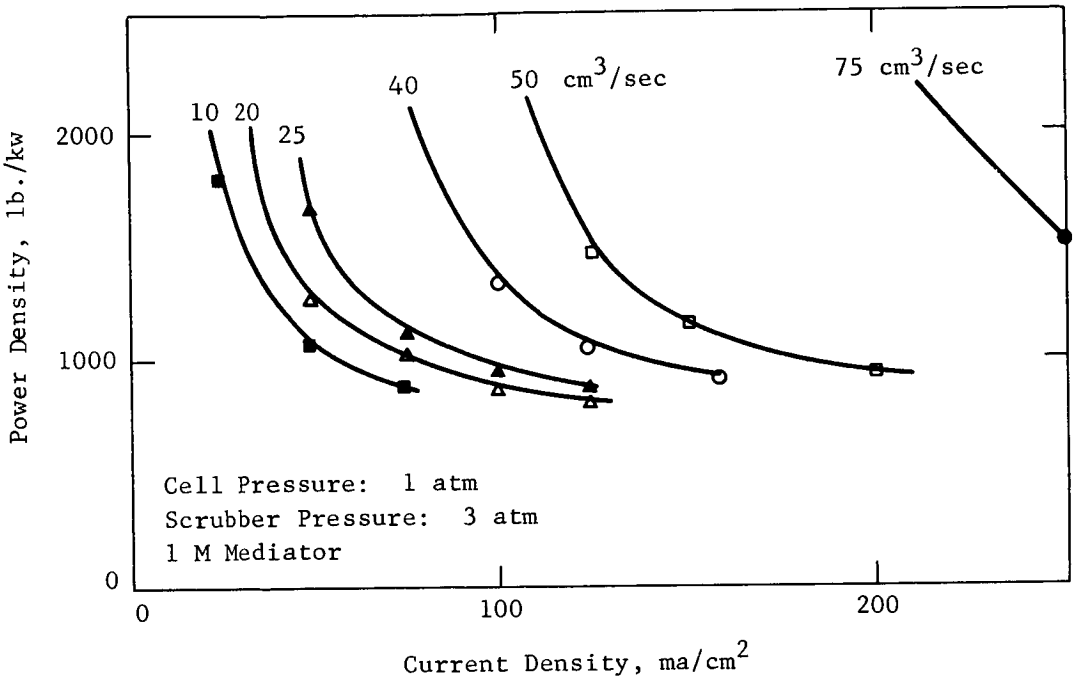
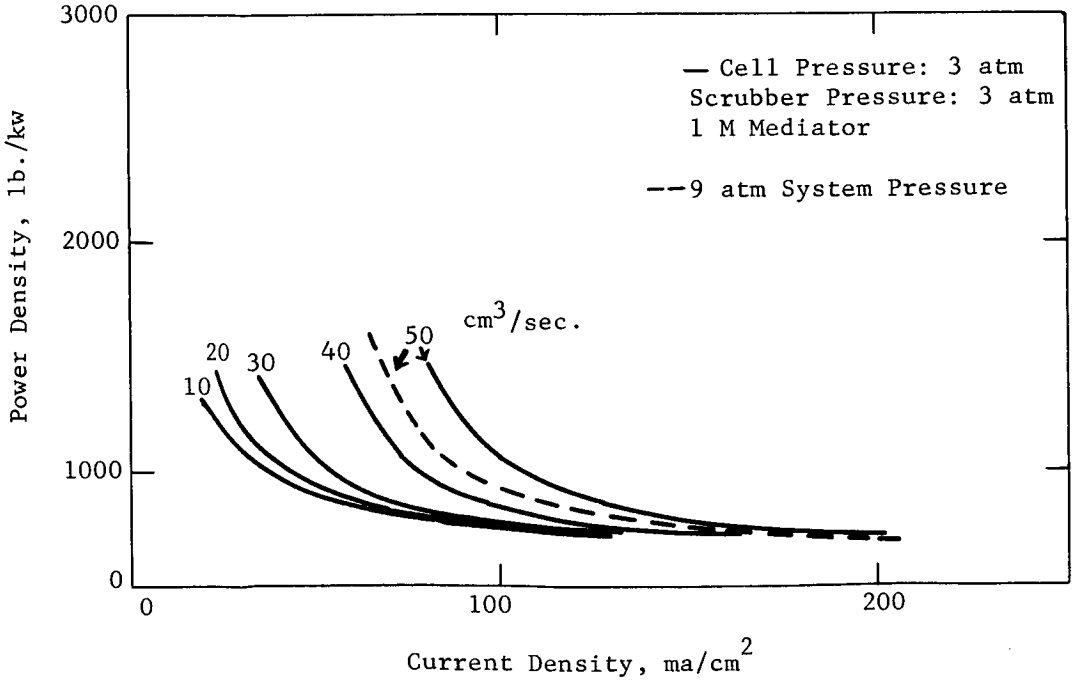


Figure 18

Power Density Pressurized Mediator Fuel Cell



SECTION V

CONCLUSIONS AND RECOMMENDATIONS

Two process concepts were examined to determine if decoupling the limiting cathodic processes into its own reaction space could result in increased H_2-O_2 fuel cell efficiency and enhanced specific power. Although this decoupling was successful the three systems examined failed to yield performance improvements even when compared to present generation interface-maintaining systems.

Part a - Moving Bed and Slurry Cathodes

Analysis of the moving catalyst - bed fuel cell concept indicates that target efficiency critically determines stack performance. Assuming ideal conditions (γ_t = 1.0) the power density obtained was well below what is currently available in conventional systems yielding a net power output of 114 w/ft^2 at 0.9 volts/cell and 186 w/ft^2 at 0.85 volts. Even under these conditions, the parasitic pumping losses amounted to over thirty percent, a totally unacceptable level. Furthermore, contacting is also dependent on catalyst agglomerate size and electrolyte flow. When this factor is included, the moving bed system becomes a net power consumer for catalyst agglomerates under 80-100 microns. Thus, it is not likely that practical power could be generated since real catalyst agglomerates rarely exceed 20 microns. The moving bed fuel cell failed to provide the anticipated improvements because the slurry flow rates required to provide high currents and useful target efficiencies introduced excessive parasitic pumping losses even at unrealistic agglomerate sizes.

The mechanical slurry system circumvents some of these problems by providing a high radial velocity for impaction and a short residence time. However, the combined effects of excessive parasitic power losses at high impeller speeds and poor impaction (collection) at low speed makes this a sharp cut-off device. To make most effective use of this system the catalyst and collector should operate near theoretical open circuit potential (50-100 mv polarized). Unfortunately, the calculations indicated that this system had no net power capability at polarizations less than 150 mv polarized. The maximum overall system efficiency (at 225 mv polarized was only 53%, compared to 60% with conventional electrodes and 65% with experimental electrode systems. Furthermore, the slurry system at best is no lighter than conventional systems,yielding a specific power of 25 lb/kw compared to 15 to 20 currently available. From the foregoing, it is obvious that both of the slurry catalyst systems do not result in overall system improvements. Therefore, no additional work in this area is recommended.

Part b - Mediator System

Analysis of the mediator fuel cell indicated that the fuel cell stack was capable of high current density at reasonable cell voltages (0.9 v). Unfortunately, the cell voltage for the 1,2 dicyano-benzoquinone was poorer than conventional electrodes. This latter performance was due to the poor E_o value, 0.97v., of this particular mediator. Performances could approach theoretical with other mediators. However, even if these improvements are made, the scrubber-regenerator would introduce an excessive weight debit. The specific power value obtained at optimistic conditions was 500 lb/kw, a level which is at least an order of magnitude poorer than the worst of the conventional fuel cells. Further work on this system is not recommended.

Part c - Recommendations

In view of these calculations, it appears that further improvement in fuel cell specific power will have to come from improvements in interface maintaining electrode structures and more active catalysts. In this regard, additional development of the Esso proprietary cathode (450 w/ft^2 at 0.9 volts) could provide significant weight economies. Despite the fact that the soluble redox mediator failed to provide a system weight improvement, an immobilized redox mediator structure (interface maintaining electrode) might be possible. This would combine the high activity or exchange current i_o of the redox cell with the good mass transport features of the wet-proofed electrode. Work in this area might lead to still further improvements in O_2 cathode performance.

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APPENDIX II-1

PARASITIC POWER CALCULATION - MOVING BED FUEL CELL

A. Collector Space Pressure Drop

The pressure drop through the collector space can be calculated using the standard screen pressure drop equation,

$$\Delta h = \frac{N}{C_D^{\,2}} \left(\frac{1-(C+1)K^2}{(C+1)K^2} \right) \frac{Q^2}{2g_c\, A^2 W^2} \qquad \text{(II-1)}$$

where C_D is the discharge coefficient, N is the number of collector wires per cm, a, and w are thickness and width of the cell in cm and K is the width of the screen opening, cm. The discharge coefficients were obtained from Figure 5-43 Perry "Chemical Engineers Handbook", Fourth Edition. For convenience the discharge coefficient data was approximated by the following relationships:

$$C_D = 0.1\ Re^{0.48} \qquad 0 < Re < 100 \qquad \text{(II-2)}$$

$$C_D = 0.37\ Re^{0.18} \qquad 100 < Re < 1000 \qquad \text{(II-3)}$$

$$C_D = 1.5 \qquad 100 < Re \qquad \text{(II-4)}$$

where $Re = K \rho_L\, Q/aw\ (C+1)k^2\, \mu_s$. These equations are used to calculate the collector power loss.

B. Regenerator - Absorber Power Loss

The regenerator-absorber used in the initial analysis is a co-current two phase flow cylindrical pipe section. Therefore, the Lockhart and Matinelli(13) correlations were used. These correlations calculate the total pressure drop from calculations of the single pressure drop of the predominant phase. That is,

$$\Delta_{P_t} = \phi_L \Delta P_L, \qquad \text{(II-5)}$$

and ϕ_L is a function of the liquid volume fraction. Thus, for laminar flow

$$\Delta_P = \phi_L \left[\frac{32hVs\,\mu s}{g_c D^2 \rho} \right] \qquad \text{(II-6)}$$

$$\phi_L = 0.54\ GLR^{-1.88} \qquad 0 < GLR < 0.6 \qquad \text{(II-7)}^*$$

$$\phi_L = GLR^{-1.37} \qquad 0.6 < GLR < 1.0 \qquad \text{(II-8)}$$

* Obtained from cross plot of Figure 5-48 and 5-49, Perry's Chemical Engineer Handbook, Fourth Edition. GLR is the gas liquid ratio.

C. Slurry Viscosity Calculation

The electrolyte slurry viscosity was calculated using equations presented in Thomas, D. G., "Physical Properties and Transport Characteristics I", IEC 55, 11, pp. 18-27, 1963. Thus,

$$\mu_s = \mu_o \left[1 + 2.5 \frac{x}{\rho_b} + 10.6 \left(\frac{x}{b}\right)^2 + 0.062 \exp \left[\frac{1.875 \frac{x}{\rho_b}}{1-1.595 \frac{x}{\rho_p}} \right] \right]; \qquad \text{(II-9)}$$

ρ_b is the bulk density of the catalyst particles (3 gm/cm^3).

APPENDIX II-2

CALCULATION OF ELECTROCHEMICAL PARAMETERS FROM POLARIZATION RELAXATION

Experimental evaluation of s, c, and i_o is important to both the moving bed and mechanical slurry system. Therefore, polarization relaxation measurements were made using a 50 mg/cm^2 interface maintaining electrode with a very open structure. (Previous studies indicated that roughly half the platinum is accessible to the gas.) The relaxation data was correlated using Equation 13 neglecting the diffusion term, and measurements were made at electrode initial polarizations ranging from 0.2 to 0.3 volts from oxygen theory. Thus, Equation 13 becomes

$$\theta_r = \frac{sc}{i_o}\left[e^{-\eta/s} - e^{-\eta e/s}\right] \qquad \text{(II-10)}$$

A plot of log θ_r vs η at low θ yields the Tafel slope S, 0.0138 volts/decade. The value of sc/i_o can be obtained from a plot of θ vs $\left[e^{-\eta e/s} - e^{-\eta e/s}\right]$. Although the deca curves gave the same Tafel slope independent of η_e at time zero, the values of sc/i_o were found to vary with the initial steady state potential, and this could not be accounted for by inclusion of the diffusion term of Equation 13 (main text). Thus, the time constant (sc/i_o) was found empirically to vary in a regular manner,

$$\left.\frac{sc}{i_o}\right|_{\eta} = \left.\frac{sc}{i_o}\right|_{\eta=o} \exp 133\, \eta_e^{2.9} \qquad \text{(II-11)}$$

where,

$$\left.\frac{sc}{i_o}\right|_{\eta=o} = 2.2 \times 10^4 \text{ (seconds)} \qquad \text{(II-11a)}$$

Since i_o cannot vary with potential and s was found to be a constant independent of η, we must conclude that the capacity term is potential dependent. This is consistent with other results on similar systems.

The i_o per gm of platinum black was calculated from a comparison of the capacitance of platinum foil and that of a truly smooth surface. Thus, the true surface per cm^2 geometric is

$$\frac{36.4 \times 10^{-6} \dfrac{F}{cm^2 \text{ (geometric)}}}{20 \times 10^{-6} \; F/cm^2 \text{(true)}} = 1.82 \text{ and the}$$

$$i_o = 5 \times 10^{-11} \frac{A}{cm^2(g)} \times \frac{1}{1.82} \frac{cm^2(g)}{cm^2(T)} \times 30 \times 10^4 \frac{cm^2(T)}{gm\ cat} = 8.25 \times 10^{-6} \frac{Amps}{gm\ cat}$$

Inserting this value into Equation 2 yields the capacitance value which is used in subsequent calculations.

$$C = 13.4 \exp 133\, \eta_e^{2.9} \left(\frac{Farads}{gm\ C}\right) \qquad \text{(II-12)}$$

APPENDIX II-3

Computer Program - Moving Bed Fuel Cell

A. Nomenclature (In order of appearance)

External

ncode	Iteration Index
ncase	Case Number
etae	Collector Polarization, volts
etaa	Anode Polarization, volts
ezero	Cell Voltage at Open Circuit, volts
rho	Resistivity, ohm cm^2
sigma	Conductivity $ohm^{-1}cm^{-1}$
c	Screen Grid Number, wires/cm
e	Screen Opening, cm^2
wird	Screen wire diameter, cm
viso	Electrolyte Viscosity, poise
viss	Slurry Viscosity, poise
ar	Air Stoichiometric Ratio
a	Cell Thickness, cm
w	Cell Width, cm
drac	Regenerator Diameter, cm
thk	Matrix Thickness, cm
h	Cell Height, cm
capac	Capacitance; Farads/gm
diflm	Diffusion limit Amps/gm Catalyst
othet	Input Time Constant, Sec (used only for alternate capacity route)
flow	Flow Iteration Value, cm^3/sec
flow 1	Flow Rate, cm^3/sec
amps	Current, amperes
volts	Operating Voltage, volts
afsq	ma/cm^2
plcl	Cell Power Loss, watts
theta	Regenerator Residence Time, sec
oxflow	Oxygen Flow Rate to Regenerator cm^3/sec
velg	Gas Velocity in Regenerator cm/sec
vell	Liquid Velocity in Regenerator cm/sec
vract	Regenerator volume, liters

wract	Regenerator Weight, lbs
plrl	Regenerator Pumping Loss, watts
pumpl	Total Pumping Loss, watts
grpow	Gross Cell Power, watts
xnepow	Net Cell Power, watts
alfas	Orifice Size, cm^2
cd	Screen Discharge Coefficient (ΔP)
rec	Reynolds Number in Cell, dimensionless

Internal

acw, expo 1, expo 2, expo 3, capax, theto, coulb, xmult, timk, glr

Note: 0 in column 6 of Fortran denotes continued statement.
4 in column 6 of Fortran denotes end of statement.

APPENDIX II-3 (Cont'd)

COMPUTER PROGRAM - MOVING BED FUEL CELL

```
101. -ready        program okren2
102. +ready c      slurry fuel cell power calculation - model two
103. +ready       0dimension flow1(30),coulb(30),amps(30),afsq(30),volts(30),
103. +ready       1grpow(30),alfas(30),viss(30),rec(30),cd(30),xmult(30),plc1(30
),
103. +ready       2phi(30),vell(30),velg(30),theta(30),vract(30),hract(30),plr1(
30),
103. +ready       3pumpl(30),xnepow(30),time(30),oxflw(30),glr(30),
103. +ready       4wract(30),timk(30),name(18)
104. +ready c
105. +ready     20 read 121 ,ncode,nocas
106. +ready        read122 ,etae,etaa,eta,ezero,rho,sigma
107. +ready        read 122 , flow,ptz,xin,xout,dens,gama
108. +ready        read 123 ,c,e, wird, viso,ar
109. +ready        read 124 , a, w, drac,thk,h
110. +ready        read 125 ,capac,diflm,othet
111. +ready        acw = 2.0* c* wird
112. +ready        stagn=(alog(xin/xout))/(acw*gama)
113. +ready        expo1=exp(72.46*etae)-exp(72.46*eta)
114. +ready        expo2=exp(-72.46*eta)-exp(-72.46*etae)
115. +ready        expo3 = (1.0-exp(-1.0*gama*acw*stagn))
116. +ready        ncode1=ncode
117. +ready    131 do 199 k=1,ncode1
118. +ready        xk=k
119. +ready        flow1(k)=flow*xk
120. +ready c      power calculation
121. +ready        if(capac-1.0)132,132,140
122. +ready    132 capak = 13.40*exp(133.0*etae**2.9)
123. +ready        theto = 2.24e+04
124. +ready        go to 141
125. +ready    140 capak = capac
126. +ready        theto = othet*10.0**4
127. +ready        go to 141
128. +ready    141 coulb(k) = flow1(k)*ptz*xin*capak*(etae-eta)
129. +ready        amps(k) = coulb(k)*expo3
130. +ready        afsq(k)=amps(k)/(h*w)
131. +ready        volts(k)=ezero-(etae+etaa+afsq(k)*((a/(2.0*sigma))+rho]]
132. +ready        grpow(k)=volts(k)*amps(k)
133. +ready        afsq(k)=afsq(k)*1000.0
134. +ready        alfas(k)=(c+1.0)*e**2.0
135. +ready c      power loss calculation
136. +ready       0viss[k]>viso*[1.0<0.833*ptz<3.50*ptz**2<0.062*exp[0.625*ptz/[
1.0-0.531*ptz
136. +ready       4]]]

137. +ready        rec(k)=dens*flow1(k)/(a*w*viss(k)*(alfas(k)/e))
138. +ready        if(rec(k)-100.0)30,30,40
139. +ready     30 cd(k)=0.1*rec(k)**0.48
140. +ready        go to 61
141. +ready     40 if(rec(k)-1000.0)50,50,60
142. +ready     50 cd(k)=0.37*rec(k)**0.18
143. +ready        go to 61
144. +ready     60 cd(k)=1.5
145. +ready     61 xmult(k)=5.20e-08*flow1(k)**3*dens/((a*w)**2)
146. +ready       0plc1(k)=xmult(k)*((1.0-alfas(k)**2.0)/((alfas(k)*cd(k))**2.0))
```

APPENDIX II-3 (Cont'd)

COMPUTER PROGRAM - MOVING BED FUEL CELL

```
*
146. +ready       4stagn
147. +ready        if(othet-1.00)62,62,63
148. +ready     62 timk(k) =  theto*exp(133.0*etae**2.9)
149. +ready        go to 64
150. +ready     63 timk(k) = 8.25e-06/(0.0138*capak)
151. +ready        go to 64
152. +ready     64 if(diflm-1.0)70,70,80
153. +ready c
154. +ready     70 theta(k) = timk(k)*expo2
155. +ready        go to 81
156. +ready     80 theta(k) = timk(k)*expo2-capak*(eta-etae)/diflm
157. +ready     81 oxflw(k) = 0.08*ar*amps(k)
158. +ready        velg(k) = oxflw(k)/(0.785*drac**2)
159. +ready        vell(k)=flowl(k)/(0.785*drac**2)
160. +ready        vract[k]>theta[k]*flowl[k]*[1.0<oxflw[k]/flowl[k]]*0.001*gama
161. +ready        hract(k) = vract(k)/(0.785*drac**2)
162. +ready        wract[k]>theta[k]*flowl[k]*dens/454.
163. +ready        glr(k) = flowl(k)/(flowl(k)+oxflw(k))
164. +ready        if(glr(k)-0.6)110,100,100
165. +ready    100 phi(k) = 1.0/(glr(k)**1.37)
166. +ready        go to 111
167. +ready    110 phi(k) = 0.54/(glr(k)**1.88)
168. +ready    111 plrl(k) = 3.02e-06*phi(k)*(hract(k)*viss(k)*flowl(k)**2)/(drac
**4)
169. +ready        pumpl(k) = plrl(k) + plcl(k)+(1.42e-06*dens)*(flowl(k)**3)
170. +ready        xnepow(k) = grpow(k)-(pumpl(k)/0.85)
171. +ready        if(xnepow(k)-1.0)113,113,191
172. +ready    113 print 129
173. +ready        go to 199
174. +ready    191 print 105
175. +ready    112  print 106 ,nocas,xk,etae,eta,ptz,xin,xout,drac
176. +ready        print 137
177. +ready        print 133,ar,flowl(k),gama,capac,othet
178. +ready        print 108
179. +ready   1200print 107 ,theta(k),vract(k),hract(k),amps(k),afsq(k),volts(k),
179. +ready       4grpow(k),plcl(k),plrl(k)
180. +ready        print 109
181. +ready       0print 138,                pumpl(k),xnepow(k),vell(k),velg(k),
181. +ready       4wract(k),glr(k),oxflw(k),alfas(k)
182. +ready    121 format (2i4)
183. +ready    129 format(22h power output negative)
184. +ready    122 format (6f10.5)
185. +ready    123 format (f10.5,2f10.6,2f10.5)
186. +ready    124 format (f10.6,2f10.5, 2f10.6)
187. +ready    125 format(3f10.5)
188. +ready    199 continue
189. +ready   1050format[ 86h nocas  xk       etae         eta          ptz
189. +ready       4 xin          xout         drac    ]
190. +ready    106 format(1x,i5,f5.0,8(3x,f10.5))
190. +note   width in field f5.0,8 is zero
191. +ready   1370format(  73h                   ar          flowl        gamma
191. +ready       4 capac        othet  )
192. +ready    133 format(14x,5(3x,f10.5))
193. +ready   1080format(82h          theta     vract    hract   amps    apsq   volts
193. +ready       4    grpow    plcl     plrl  )
194. +ready   1070format[9x,f6.0,3x,f7.0,3x,f5.3,2x,f5.1,3x,f5.1,3x,f6.3,2x,f6.1,3x,
194. +ready       4f6.2,4x,f6.4]
194. +note   width in field f6.0,3 is zero
194. +note   width in field f7.0,3 is zero
195. +ready    1090 format[  85h          pumpl   xnepow     vell     velg      wract
195. +ready       4      grl     oxflw      alfas ]
196. +ready    138 format[8x,f7.2,2x,f6.1,3x,f6.2,3x,f6.2,3x,f7.0,3[3x,f6.3],/]
196. +note   width in field f7.0,3 is zero
197. +ready    198 stop
198. +ready        end
```

APPENDIX II-4

CALCULATED RESULTS - MOVING BED FUEL CELL

```
199. *ready        save
199. *ready       check
     check *    20       +105.
     check *   112       +175.
     check *   120       +179.
     check *   131       +117.
     check *   198       +197.
     check *expo1        +113.
     check *name          103.
     check *okren2       +101.
     check *thk          +109.
     check *time          103.
199. *ready      start(0)
105. =i121    20   1
106. =i122      0.200     0.00      0.070     1.17      0.15      0.278
107. =i122     10.0       0.10      1.0       0.10      1.55      1.0
108. =i123     20.0       0.0297    0.0188    0.014     1.0
109. =i124      0.20     24.0      15.24      0.050    14.0
110. =i125      0.0       0.0       0.0
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1   1.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000    10.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.       5.       0.028    5.5    16.3    0.962     5.3      0.03      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138           0.03      5.2       0.05     0.00      17.     0.958    0.438     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1   2.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000    20.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      10.       0.056   10.9    32.6    0.953    10.4      0.18      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138           0.20      10.2      0.11     0.00      33.     0.958    0.875     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1   3.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000    30.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      15.       0.084   16.4    48.8    0.945    15.5      0.52      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138           0.58      14.8      0.16     0.01      50.     0.958    1.313     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1   4.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000    40.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      20.       0.112   21.9    65.1    0.937    20.5      0.89      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138           1.03      19.3      0.22     0.01      67.     0.958    1.751     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1   5.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000    50.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      26.       0.140   27.4    81.4    0.929    25.4      1.73      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138           2.01      23.0      0.27     0.01      84.     0.958    2.188     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1   6.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000    60.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      31.       0.168   32.8    97.7    0.920    30.2      3.00      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138           3.47      26.1      0.33     0.01     100.     0.958    2.626     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1   7.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000    70.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      36.       0.196   38.3   114.0    0.912    34.9      4.76      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138           5.51      28.4      0.38     0.02     117.     0.958    3.064     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1   8.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000    80.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      41.       0.224   43.8   130.3    0.904    39.5      7.10      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138           8.23      29.9      0.44     0.02     134.     0.958    3.501     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1   9.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000    90.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      46.       0.252   49.2   146.5    0.895    44.1     10.11      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138          11.72      30.3      0.49     0.02     151.     0.958    3.939     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1  10.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000   100.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      51.       0.280   54.7   162.8    0.887    48.5     13.87      0.0000
180. =o109          pumpl    xnepow      vell     velg     wract       grl      oxflw      alfas
181. =o138          16.07      29.6      0.55     0.02     167.     0.958    4.377     0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xin         xout        drac
175. =o106      1  11.      0.20000     0.07000     0.10000     1.00000     0.10000    15.24000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                   1.00000   110.00000     1.00000     0.          0.
178. =o108          theta     vract      hract   amps    apsq    volts    grpow     plcl      plrl
179. =o107           490.      56.       0.309   60.2   179.1    0.879    57.9      18.46     0.0000
```

APPENDIX II-4 (Cont'd)

CALCULATED RESULTS - MOVING BED FUEL CELL

```
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138           21.39    27.7    0.60     0.03      184.     0.958     4.815     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      1  12.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   120.00000  1.00000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     61.    0.337    65.7    195.4   0.870     57.1    23.97    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138           27.77    24.5    0.66     0.03      201.     0.958     5.252     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      1  13.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   130.00000  1.00000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     66.    0.365    71.1    211.7   0.862     61.3    30.47    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138           35.31    19.8    0.71     0.03      217.     0.958     5.690     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      1  14.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   140.00000  1.00000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     72.    0.393    76.6    228.0   0.854     65.4    38.06    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138           44.10    13.5    0.77     0.03      234.     0.958     6.128     0.019
181. =break  181.
199. +ready       start(0)
105. =I121    20    2
106. =I122     0.200     0.00      0.070     1.17      0.15      0.278
107. =I122    10.0      0.10       1.0      0.10      1.55       .75
108. =I123    20.0     0.0297    0.0188     0.014     1.0
109. =I124    0.200    24.0      15.24     0.050     14.0
110. =I125    0.0       0.0       0.0
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2   1.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   10.00000   0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.      4.    0.021     5.5     16.3   0.962      5.3     0.04    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138            0.04     5.2    0.05     0.00       17.     0.958     0.438     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2   2.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   20.00000   0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.      8.    0.042    10.9     32.6   0.953     10.4     0.24    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138            0.26    10.1    0.11     0.00       33.     0.958     0.875     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2   3.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   30.00000   0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     12.    0.063    16.4     48.8   0.945     15.5     0.70    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138            0.76    14.6    0.16     0.01       50.     0.958     1.313     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2   4.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   40.00000   0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     15.    0.084    21.9     65.1   0.937     20.5     1.18    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138            1.32    18.9    0.22     0.01       67.     0.958     1.751     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2   5.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   50.00000   0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     19.    0.105    27.4     81.4   0.929     25.4     2.31    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138            2.59    22.4    0.27     0.01       84.     0.958     2.188     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2   6.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   60.00000   0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     23.    0.126    32.8     97.7   0.920     30.2     3.99    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138            4.47    24.9    0.33     0.01      100.     0.958     2.626     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2   7.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   70.00000   0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     27.    0.147    38.3    114.0   0.912     34.9     6.34    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138            7.10    26.6    0.38     0.02      117.     0.958     3.064     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2   8.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   80.00000   0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     31.    0.168    43.8    130.3   0.904     39.5     9.47    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138           10.60    27.1    0.44     0.02      134.     0.958     3.501     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2   9.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   90.00000   0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     35.    0.189    49.2    146.5   0.895     44.1    13.48    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138           15.09    26.3    0.49     0.02      151.     0.958     3.939     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2  10.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   100.00000  0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     38.    0.210    54.7    162.8   0.887     48.5    18.49    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138           20.69    24.2    0.55     0.02      167.     0.958     4.377     0.019
181. =    2
174. =o105   nocas  xk      etae        eta        ptz        xln        xout        drac
175. =o106      2  11.    0.20000     0.07000    0.10000    1.00000    0.10000    15.24000
176. =o137                  ar        flow1     gamma      capac      othet
177. =o133                  1.00000   110.00000  0.75000    0.         0.
178. =o108          theta    vract    hract    amps     apsq   volts    grpow     plcl     plrl
179. =o107           490.     42.    0.231    60.2    179.1   0.879     52.9    24.61    0.0000
180. =o109          pumpl   xnepow    vell     velg     wract       grl     oxflw      alfas
181. =o138           27.54    20.5    0.60     0.03      184.     0.958     4.815     0.019
181. =break  181.
```

APPENDIX II-4 (Cont'd)

CALCULATED RESULTS - MOVING BED FUEL CELL

```
199. +ready        start(0)
105. =i121     10   3
106. =i122      0.200      0.00       0.070      1.17       0.15       0.278
107. =i122     10.0        0.10       1.0        0.10       1.55        .50
108. =i123     20.0       0.0297     0.0188      0.014      1.0
109. =i124     0.200      24.0       15.24       .050      14.0
110. =i125     0.0        0.0        0.0
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3   1.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000      10.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.        3.     0.014    5.5     16.3    0.962     5.3      0.06     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138              0.06      5.2      0.05     0.00       17.     0.958    0.438     0.019
181. =     2
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3   2.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000      20.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.        5.     0.028   10.9     32.6    0.953    10.4      0.36     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138              0.38     10.0      0.11     0.00       33.     0.958    0.875     0.019
181. =     2
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3   3.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000      30.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.        8.     0.042   16.4     48.8    0.945    15.5      1.05     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138              1.11     14.2      0.16     0.01       50.     0.958    1.313     0.019
181. =     2
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3   4.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000      40.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.       10.     0.056   21.9     65.1    0.937    20.5      1.78     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138              1.92     18.2      0.22     0.01       67.     0.958    1.751     0.019
181. =     2
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3   5.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000      50.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.       13.     0.070   27.4     81.4    0.929    25.4      3.47     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138              3.74     21.0      0.27     0.01       84.     0.958    2.188     0.019
181. =     2
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3   6.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000      60.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.       15.     0.084   32.8     97.7    0.920    30.2      5.99     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138              6.47     22.6      0.33     0.01      100.     0.958    2.626     0.019
181. =     2
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3   7.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000      70.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.       18.     0.098   38.3    114.0    0.912    34.9      9.51     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138             10.27     22.8      0.38     0.02      117.     0.958    3.064     0.019
181. =     2
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3   8.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000      80.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.       20.     0.112   43.8    130.3    0.904    39.5     14.20     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138             15.33     21.5      0.44     0.02      134.     0.958    3.501     0.019
181. =     2
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3   9.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000      90.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.       23.     0.126   49.2    146.5    0.895    44.1     20.22     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138             21.83     18.4      0.49     0.02      151.     0.958    3.939     0.019
181. =     2
174. =o105    nocas  xk        etae          eta           ptz           xin           xout          drac
175. =o106        3  10.       0.20000       0.07000       0.10000       1.00000       0.10000      15.24000
176. =o137                     ar            flow1         gamma         capac         othet
177. =o133                       1.00000     100.00000       0.50000       0.            0.
178. =o108            theta      vract     hract   amps     apsq   volts    grpow     plcl      plrl
179. =o107              490.       26.     0.140   54.7    162.8    0.887    48.5     27.74     0.0000
180. =o109            pumpl    xnepow      vell     velg      wract          grl      oxflw      alfas
181. =o138             29.94     13.3      0.55     0.02      167.     0.958    4.377     0.019
181. =     2
```

APPENDIX II-4 (Cont'd)

CALCULATED RESULTS - MOVING BED FUEL CELL

```
197. =stop
199. +ready       start(0)
105. =i121    10   6
106. =i122     0.200     0.00      0.070     1.17      0.15      0.278
107. =i122    10.0       0.1       1.0        .10      1.55      0.25
108. =i123    20.0       .0297     .0188      .014     1.0
109. =i124     .20      24.0      15.25       .050    14.
110. =i125    0.0       0.0       0.0
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      6   1.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    10.00000     0.25000     0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       1.    0.007    5.5    16.3    0.962     5.3     0.12    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138              0.12     5.1     0.05     0.00      17.    0.958    0.438    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      6   2.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    20.00000     0.25000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       3.    0.014   10.9    32.6    0.953    10.4     0.72    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138              0.74     9.6     0.11     0.00      33.    0.958    0.875    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      6   3.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    30.00000     0.25000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       4.    0.021   16.4    48.8    0.945    15.5     2.10    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138              2.16    13.0     0.16     0.01      50.    0.958    1.313    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      6   4.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    40.00000     0.25000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       5.    0.028   21.9    65.1    0.937    20.5     3.55    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138              3.69    16.2     0.22     0.01      67.    0.958    1.751    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      6   5.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    50.00000     0.25000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       6.    0.035   27.4    81.4    0.929    25.4     6.93    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138              7.21    16.9     0.27     0.01      84.    0.958    2.188    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      6   6.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    60.00000     0.25000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       8.    0.042   32.8    97.7    0.920    30.2    11.98    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138             12.46    15.5     0.33     0.01     100.    0.958    2.626    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      6   7.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    70.00000     0.25000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       9.    0.049   38.3   114.0    0.912    34.9    19.03    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138             19.78    11.6     0.38     0.02     117.    0.958    3.064    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      6   8.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    80.00000     0.25000     0.          0.
6
177. =break  177.
199. +ready       start(0)
105. =i121    10   7
106. =i122     0.200     0.00      0.070     1.17      0.15      0.278
107. =i122    10.0       0.1       1.0        .10      1.55      0.1
108. =i123    20.0      0.0297    0.0188     0.014     1.0
109. =i124     0.20     24.0      15.25       .050    14.
110. =i125     0.0       0.0       0.0
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      7   1.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    10.00000     0.10000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       1.    0.003    5.5    16.3    0.962     5.3     0.29    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138              0.29     4.9     0.05     0.00      17.    0.958    0.438    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      7   2.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000

176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    20.00000     0.10000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       1.    0.006   10.9    32.6    0.953    10.4     1.80    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138              1.81     8.3     0.11     0.00      33.    0.958    0.875    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      7   3.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    30.00000     0.10000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       2.    0.008   16.4    48.8    0.945    15.5     5.24    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138              5.30     9.3     0.16     0.01      50.    0.958    1.313    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      7   4.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    40.00000     0.10000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       2.    0.011   21.9    65.1    0.937    20.5     8.88    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138              9.02     9.9     0.22     0.01      67.    0.958    1.751    0.019
181. =     2
174. =o105   nocas  xk        etae        eta         ptz         xln         xout        drac
175. =o106      7   5.      0.20000     0.07000     0.10000     1.00000     0.10000     15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    50.00000     0.10000     0.          0.
178. =o108            theta     vract    hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107              490.       3.    0.014   27.4    81.4    0.929    25.4    17.34    0.0000
180. =o109            pumpl   xnepow     vell     velg     wract       grl     oxflw     alfas
181. =o138             17.61     4.7     0.27     0.01      84.    0.958    2.188    0.019
181. =     2
```

APPENDIX II-4 (Cont'd)

CALCULATED RESULTS - MOVING BED FUEL CELL

```
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
197. *stop
193. +ready       start(0)
105. *i121    10   7
106. *i122     0.200      0.00       0.070      1.17       0.15       0.278
107. *i122    10.0        0.1        1.0        0.10       1.55       0.05
108. *i123    20.0       0.0297     0.0188      0.014      1.0
109. *i124     0.20      24.0       15.25       .050      14.
110. *i125     0.0        0.0        0.0
174. *o105   nocas  xk        etae          eta           ptz           xin           xout          drac
175. *o106      7   1.       0.20000       0.07000       0.10000       1.00000       0.10000       15.25000
176. *o137                     ar            flow1         gamma         capac         othet
177. *o133                       1.00000      10.00000       0.05000       0.            0.
178. *o108            theta      vract         hract         amps          apsq          volts         grpow         plcl          plrl
179. *o107              490.        0.         0.001         5.5          16.3          0.962         5.3           0.58          0.0000
180. *o109            pumpl      xnepow        vell          velg          wract         grl           oxflw         alfas
181. *o138              0.58       4.6         0.05          0.00           17.          0.958         0.438         0.019
181. =     2
174. *o105   nocas  xk        etae          eta           ptz           xin           xout          drac
175. *o106      7   2.       0.20000       0.07000       0.10000       1.00000       0.10000       15.25000
176. *o137                     ar            flow1         gamma         capac         othet
177. *o133                       1.00000      20.00000       0.05000       0.            0.
178. *o108            theta      vract         hract         amps          apsq          volts         grpow         plcl          plrl
179. *o107              490.        1.         0.005        10.9          32.6          0.953         10.4          3.59          0.0000
180. *o109            pumpl      xnepow        vell          velg          wract         grl           oxflw         alfas
181. *o138              3.61       6.2         0.11          0.00           33.          0.958         0.875         0.019

181. =     2
174. *o105   nocas  xk        etae          eta           ptz           xin           xout          drac
175. *o106      7   3.       0.20000       0.07000       0.10000       1.00000       0.10000       15.25000
176. *o137                     ar            flow1         gamma         capac         othet
177. *o133                       1.00000      30.00000       0.05000       0.            0.
178. *o108            theta      vract         hract         amps          apsq          volts         grpow         plcl          plrl
179. *o107              490.        1.         0.004        16.4          48.8          0.945         15.5          10.48         0.0000
180. *o109            pumpl      xnepow        vell          velg          wract         grl           oxflw         alfas
181. *o138             10.54       3.1         0.16          0.01           50.          0.958         1.313         0.019
181. =     2
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
197. *stop

             start(0)
105. *i121    10   7
106. *i122     0.200      0.00       0.070      1.17       0.15       0.278
107. *i122    10.0        0.1        1.0        0.10       1.55       0.01
108. *i123    20.0       0.0297     0.0188      0.014      1.0
109. *i124     0.20      24.0       15.25       .050      14.
110. *i125     0.0        0.0        0.0
174. *o105   nocas  xk        etae          eta           ptz           xin           xout          drac
175. *o106      7   1.       0.20000       0.07000       0.10000       1.00000       0.10000       15.25000
176. *o137                     ar            flow1         gamma         capac         othet
177. *o133                       1.00000      10.00000       0.01000       0.            0.
178. *o108            theta      vract         hract         amps          apsq          volts         grpow         plcl          plrl
179. *o107              490.        0.         0.000         5.5          16.3          0.962         5.3           2.88          0.0000
180. *o109            pumpl      xnepow        vell          velg          wract         grl           oxflw         alfas
181. *o138              2.89       1.9         0.05          0.00           17.          0.958         0.438         0.019
181. =     2
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
197. *stop
199. +ready       start(0)
105. *i121    10   8
106. *i122      .100      0.00       0.070      1.17       0.15       0.278
107. *i122    10.0        .1         1.0        0.10       1.55       1.0
108. *i123    20.0       0.0297     0.0188      0.014      1.0
109. *i124     0.20      24.0       15.25      0.050      14.0
110. *i125     0.0        0.0        0.0
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
172. *o129   power output negative
197. *stop
199. +ready       start(0)
105. *i121    20   9
106. *i122      .300      0.00       0.070      1.17       0.15       0.278
107. *i122    10.0        .10        1.0        0.10       1.55       1.0
108. *i123    20.0       .0297      .0188       0.14       1.0
109. *i124     .20      24.0       15.25        .050      14.0
110. *i125     0.0        0.0        0.0
174. *o105   nocas  xk        etae          eta           ptz           xin           xout          drac
175. *o106      9   1.       0.30000       0.07000       0.10000       1.00000       0.10000       15.25000
176. *o137                     ar            flow1         gamma         capac         othet
177. *o133                       1.00000      10.00000       1.00000       0.            0.
178. *o108            theta      vract         hract         amps          apsq          volts         grpow         plcl          plrl
179. *o107              8063.     183.        1.004       159.3         474.0          0.628         100.1         0.11          0.0000
180. *o109            pumpl      xnepow        vell          velg          wract         grl           oxflw         alfas
181. *o138              0.12      99.9         0.05          0.07           275.         0.440        12.742         0.019
181. =     2
174. *o105   nocas  xk        etae          eta           ptz           xin           xout          drac
175. *o106      9   2.       0.30000       0.07000       0.10000       1.00000       0.10000       15.25000
176. *o137                     ar            flow1         gamma         capac         othet
177. *o133                       1.00000      20.00000       1.00000       0.            0.
178. *o108            theta      vract         hract         amps          apsq          volts         grpow         plcl          plrl
179. *o107              8063.     567.        2.009       318.6         948.1          0.387         123.2         0.47          0.0000
180. *o109            pumpl      xnepow        vell          velg          wract         grl           oxflw         alfas
181. *o138              0.49     122.6         0.11          0.14           551.         0.440        25.485         0.019
181. =     2
174. *o105   nocas  xk        etae          eta           ptz           xin           xout          drac
175. *o106      9   3.       0.30000       0.07000       0.10000       1.00000       0.10000       15.25000
176. *o137                     ar            flow1         gamma         capac         othet
177. *o133                       1.00000      30.00000       1.00000       0.            0.
178. *o108            theta      vract         hract         amps          apsq          volts         grpow         plcl          plrl
179. *o107              8063.     550.        3.013       477.8         422.1          0.145         69.3          1.08          0.0000
180. *o109            pumpl      xnepow        vell          velg          wract         grl           oxflw         alfas
181. *o138              1.14      68.0         0.16          0.21           826.         0.440        38.227         0.019
181. =     2
```

APPENDIX II-4 (Cont'd)

CALCULATED RESULTS - MOVING BED FUEL CELL

```
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
172. =o129   power output negative
197. =stop
199. +ready      start(0)
105. =i121    10  10
106. =i122     0.200     0.00      0.070     1.17      0.15      0.278
107. =i122     10.       0.2       1.0       0.1       1.55      1.0
108. =i123     20.       .0297     .0188     .014      1.0
109. =i124     0.20      24.0      15.25     .050      14.
110. =i125     0.0       0.0       0.0
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   1.     0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   10.00000  1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      5.      0.029     10.9      32.6      0.953     10.4      0.03      0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            0.03      10.4      0.05      0.00      17.       0.920     0.875     0.019
181. =    2
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   2.     0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   20.00000  1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      11.     0.058     21.9      65.1      0.937     20.5      0.19      0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            0.21      20.3      0.11      0.01      33.       0.920     1.751     0.019
181. =    2
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   3.     0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   30.00000  1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      16.     0.088     32.8      97.7      0.920     30.2      0.55      0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            0.61      29.5      0.16      0.01      50.       0.920     2.626     0.019
181. =    2
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   4.     0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   40.00000  1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      21.     0.117     43.8      130.3     0.904     39.5      0.89      0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            1.03      38.3      0.22      0.02      67.       0.920     3.501     0.019
181. =    2
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   5.     0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   50.00000  1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      27.     0.146     54.7      162.8     0.887     48.5      1.73      0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            2.01      46.2      0.27      0.02      84.       0.920     4.377     0.019
181. =    2
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   6.     0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   60.00000  1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      32.     0.175     65.7      195.4     0.870     57.1      3.00      0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            3.47      53.1      0.33      0.03      100.      0.920     5.252     0.019
181. =    2
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   7.     0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   70.00000  1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      37.     0.204     76.6      228.0     0.854     65.4      4.76      0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            5.51      58.9      0.38      0.03      117.      0.920     6.128     0.019
181. =    2
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   8.     0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   80.00000  1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      43.     0.234     87.5      260.5     0.857     73.3      7.10      0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            8.23      63.6      0.44      0.04      134.      0.920     7.003     0.019
181. =    2
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   9.     0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   90.00000  1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      48.     0.263     98.5      293.1     0.821     80.8      10.11     0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            11.72     67.0      0.49      0.04      151.      0.920     7.878     0.019
181. =    2
174. =o105   nocas  xk      etae      eta       ptz       xin       xout      drac
175. =o106     10   10.    0.20000   0.07000   0.20000   1.00000   0.10000   15.25000
176. =o137                 ar        flow1     gamma     capac     othet
177. =o133                 1.00000   100.00000 1.00000   0.        0.
178. =o108          theta     vract     hract     amps      apsq      volts     grpow     plcl      plrl
179. =o107            490.      53.     0.292     109.4     325.7     0.804     88.0      13.87     0.0000
180. =o109          pumpl     xnepow    vell      velg      wract     grl       oxflw     alfas
181. =o138            16.07     69.1      0.55      0.05      167.      0.920     8.754     0.019
181. =    2
```

APPENDIX II-4 (Cont'd)

CALCULATED RESULTS - MOVING BED FUEL CELL

```
197. =stop
199. +ready      start(0)
105. =I121    10  11
106. =I122     0.200     0.00      0.070     1.17      0.15      0.278
107. =I122     25.0      0.2       1.0       0.1       1.55      1.0
108. =I123     20.       .0297     .0188     .014      1.0
109. =I124     0.20      24.0      15.25     .050      14.0
110. =I125     0.0       0.0       0.0
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     11   1.     0.20000     0.07000     0.20000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000    25.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     13.       0.075   27.4    81.4    0.929   25.4    0.34    0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138            0.38   25.0        0.14    0.01    42.     0.920   2.188   0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     11   2.     0.20000     0.07000     0.20000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000    50.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     27.       0.146   54.7    162.8   0.887   48.5    1.73    0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138            2.01   46.2        0.27    0.02    84.     0.920   4.377   0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     11   3.     0.20000     0.07000     0.20000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000    75.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     40.       0.219   82.1    244.2   0.846   69.4    5.85    0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138            6.78   61.4        0.41    0.04    125.    0.920   6.565   0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     11   4.     0.20000     0.07000     0.20000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000   100.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     53.       0.292   109.4   325.7   0.804   88.0    13.87   0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138           16.07   69.1        0.55    0.05    167.    0.920   8.754   0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     11   5.     0.20000     0.07000     0.20000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000   125.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     67.       0.365   136.8   407.1   0.763   104.3   27.09   0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138           31.39   67.4        0.68    0.06    209.    0.920   10.942  0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     11   6.     0.20000     0.07000     0.20000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000   150.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     80.       0.438   164.1   488.5   0.721   118.3   46.81   0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138           54.24   54.5        0.82    0.07    251.    0.920   13.130  0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     11   7.     0.20000     0.07000     0.20000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000   175.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     93.       0.511   191.5   569.9   0.680   130.1   74.33   0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
180. =break   180.
199. +ready      start(0)
105. =I121    20  13
106. =I122     0.200     0.00      0.070     1.17      0.15      0.278
107. =I122     10.       .40       1.0       .1        1.55      1.0
108. =I123     20.       .0297     .0188     .014      1.0
109. =I124     .20       24.0      15.25     .050      14.
110. =I125     0.0       0.0       0.0
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     13   1.     0.20000     0.07000     0.40000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000    10.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.      6.       0.032   21.9    65.1    0.937   20.5    0.03    0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138            0.04   20.5        0.05    0.01    17.     0.851   1.751   0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     13   2.     0.20000     0.07000     0.40000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000    20.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     12.       0.063   43.8    130.3   0.904   39.5    0.22    0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138            0.23   39.3        0.11    0.02    33.     0.851   3.501   0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     13   3.     0.20000     0.07000     0.40000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000    30.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     17.       0.095   65.7    195.4   0.870   57.1    0.63    0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138            0.69   56.3        0.16    0.03    50.     0.851   5.252   0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     13   4.     0.20000     0.07000     0.40000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000    40.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     23.       0.126   87.5    260.5   0.837   73.3    1.35    0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138            1.49   71.5        0.22    0.04    67.     0.851   7.003   0.019
181. =    2
174. =o105   nocas  xk      etae        eta         ptz         xin         xout        drac
175. =o106     13   5.     0.20000     0.07000     0.40000     1.00000     0.10000     15.25000
176. =o137                  ar          flow1       gamma       capac       othet
177. =o133                   1.00000    50.00000    1.00000     0.          0.
178. =o108          theta    vract       hract   amps    apsq    volts   grpow   plcl    plrl
179. =o107            490.     29.       0.158   109.4   325.7   0.804   88.0    2.43    0.0000
180. =o109          pumpl    xnepow      vell    velg    wract       grl     oxflw   alfas
181. =o138            2.70   84.8        0.27    0.05    84.     0.851   8.754   0.019
181. =    2
```

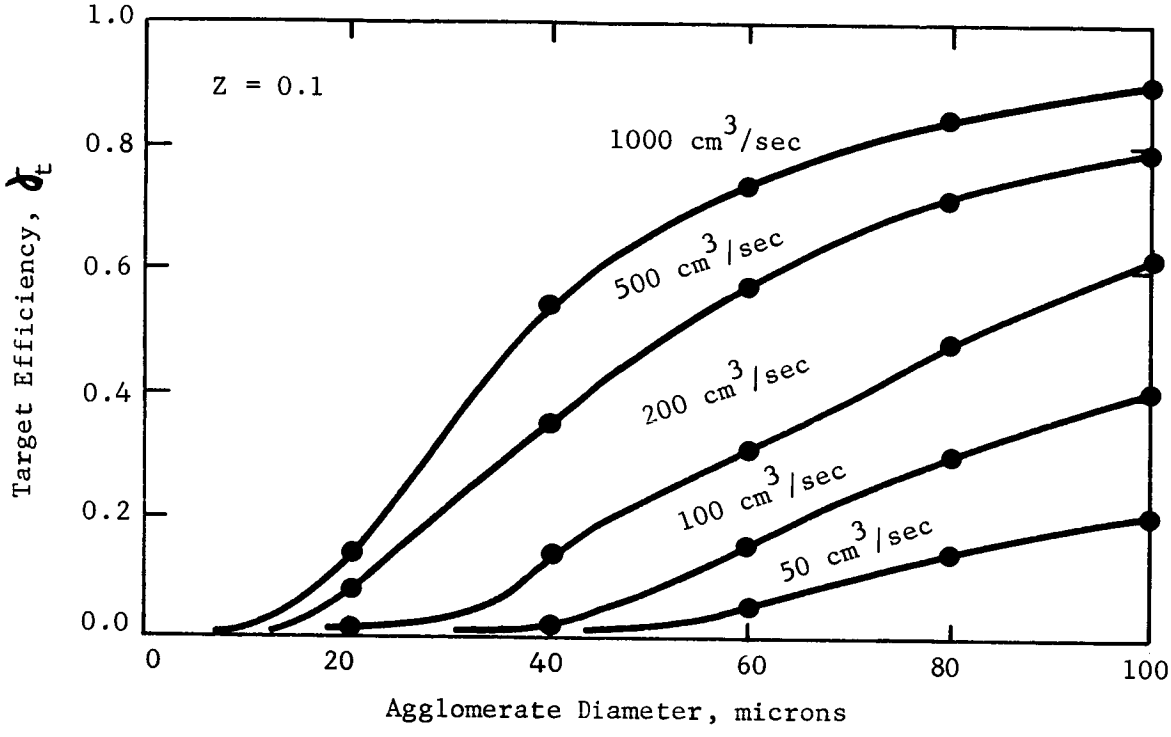
APPENDIX II-4 (Cont'd)

CALCULATED RESULTS - MOVING BED FUEL CELL

```
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     13   6.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    60.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      35.    0.189  131.3   390.8   0.771    101.2    3.00   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138            3.47    97.1     0.33    0.06      100.    0.851   10.504    0.019
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     13   7.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    70.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      40.    0.221  153.2   455.9   0.738    113.0    4.76   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138            5.51    106.5     0.38    0.07      117.    0.851   12.255    0.019
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     13   8.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    80.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      46.    0.252  175.1   521.1   0.704    123.3    7.10   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138            8.23    113.6     0.44    0.08      134.    0.851   14.006    0.019
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     13   9.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    90.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      52.    0.284  197.0   586.2   0.671    132.2   10.11   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138           11.72    118.4     0.49    0.09      151.    0.851   15.757    0.019
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     13  10.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000   100.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      58.    0.315  218.8   651.3   0.638    139.6   13.87   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138           16.07    120.7     0.55    0.10      167.    0.851   17.507    0.019
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     13  11.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000   110.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      63.    0.347  240.7   716.4   0.605    145.6   18.46   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138           21.39    120.4     0.60    0.11      184.    0.851   19.258    0.019
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     13  12.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000   120.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      69.    0.378  262.6   781.6   0.572    150.1   23.97   0.0000
179. =break  179.
199. +ready      start(0)
105. =I121    20  18
106. =I122     0.200     0.00      0.070     1.17      0.15      0.278
107. =I122     10.        .4        1.0       .10      1.55       1.0
108. =I123      8.       .084       .042      .014      1.0
109. =I124      .2        24.      15.25      .050      14.
110. =I125     0.0        0.0       0.0
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     18   1.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    10.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.       6.    0.032   21.9    65.1   0.937     20.5    0.00   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138            0.01     20.5     0.05    0.01       17.    0.851    1.751    0.064
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     18   2.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    20.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      12.    0.063   43.8   130.3   0.904     39.5    0.02   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138            0.04     39.5     0.11    0.02       33.    0.851    3.501    0.064
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     18   3.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
-
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     18   3.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    30.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      17.    0.095   65.7   195.4   0.870     57.1    0.06   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138            0.12     57.0     0.16    0.03       50.    0.851    5.252    0.064
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     18   4.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    40.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      23.    0.126   87.5   260.5   0.837     73.3    0.14   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138            0.28     73.0     0.22    0.04       67.    0.851    7.003    0.064
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     18   5.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    50.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      29.    0.158  109.4   325.7   0.804     88.0    0.25   0.0000
180. =o109          pumpl    xnepow     vell    velg     wract       grl     oxflw     alfas
181. =o138            0.52     87.4     0.27    0.05       84.    0.851    8.754    0.064
181. =     2
174. =o105   nocas  xk       etae        eta         ptz         xin         xout        drac
175. =o106     18   6.      0.20000     0.07000     0.40000     1.00000     0.10000    15.25000
176. =o137                    ar         flow1       gamma       capac       othet
177. =o133                  1.00000    60.00000     1.00000      0.          0.
178. =o108          theta     vract     hract   amps    apsq   volts    grpow    plcl     plrl
179. =o107            490.      35.    0.189  131.3   390.8   0.771    101.2    0.40   0.0000
179. =break  179.
199. +ready
```

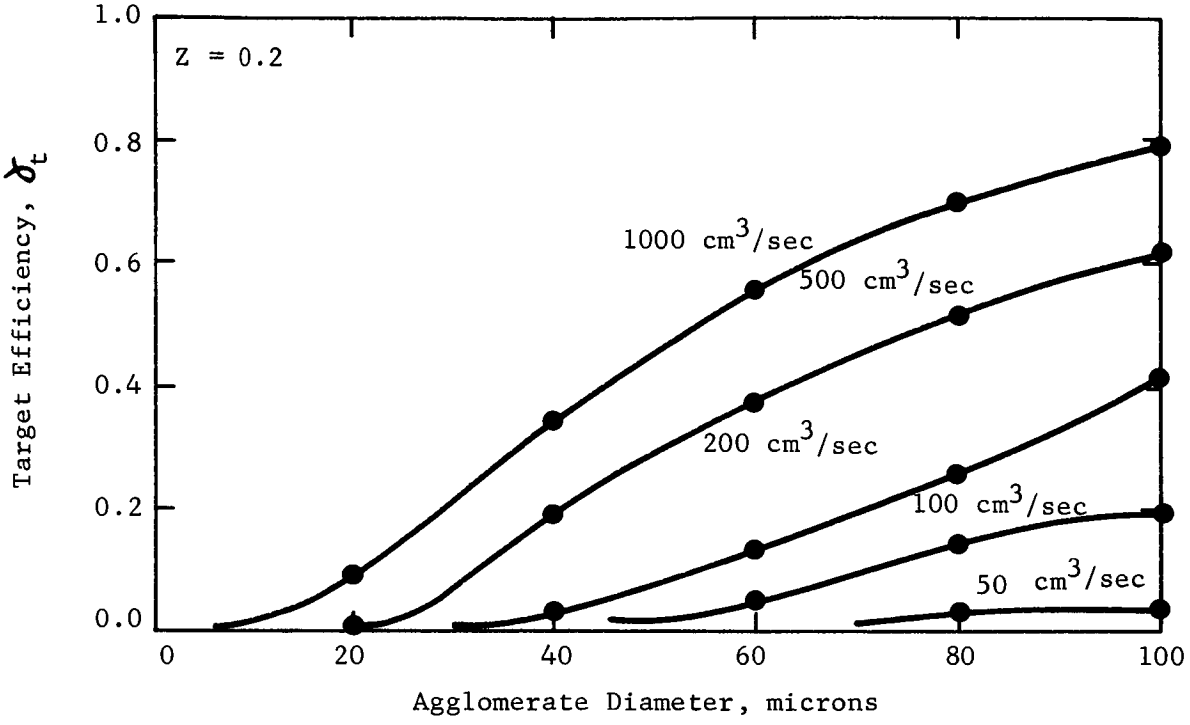
APPENDIX II-5

TARGET EFFICIENCY MOVING BED CELL



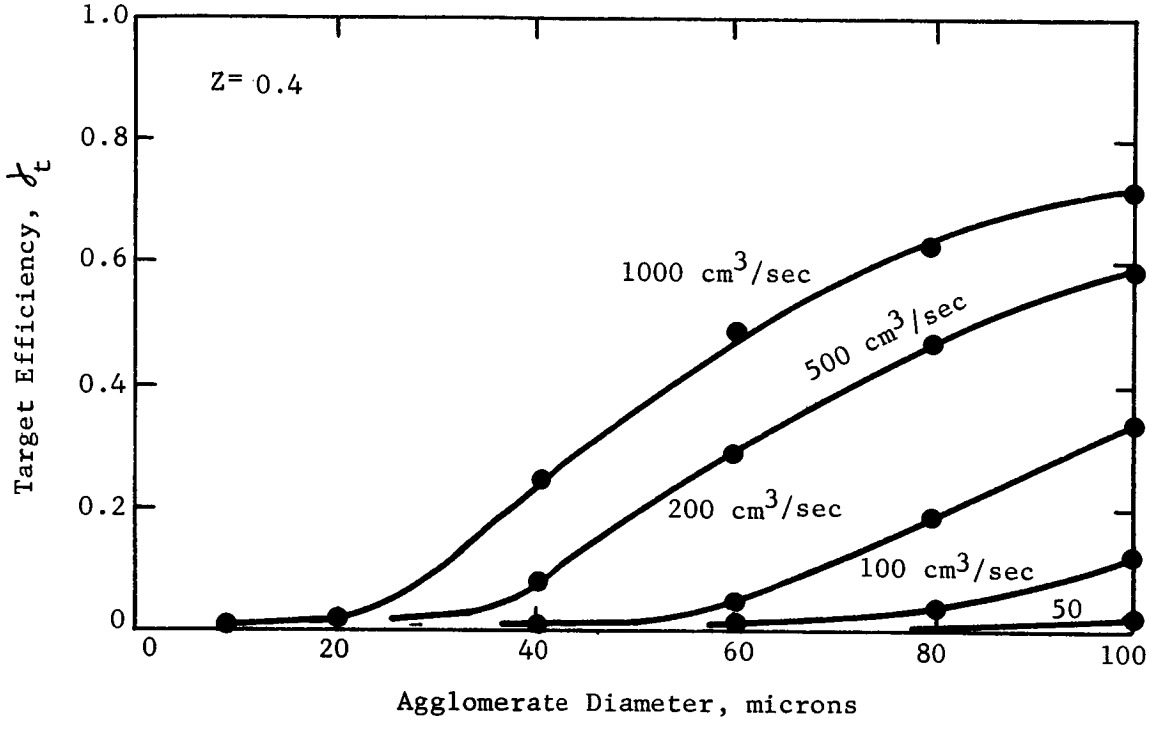
APPENDIX II-6

TARGET EFFICIENCY MOVING BED CELL



APPENDIX II-7

TARGET EFFICIENCY - MOVING BED CELL



APPENDIX III-1

SLURRY FUEL CELL MODEL THREE (MECHANICAL)

Nomenclature

as	Ratio collector area/total area impacted
amp	Current, amps
afsq	Current Density, ma/cm^2
code	Print Control Variable
capac	Capacitance Farads/gm Catalyst (External)
capak	Capacitance Farads/gm (Calculated)
celdo	Initial Value of Cell Diameter, cm
cdel	Increment in Cell Diameter
dp	Catalyst Agglomerate Radius, cm
dmp	Impeller Diameter, cm
ddel	Increment in Impeller Diameter
dens	Electrolyte Density, gm/cm^3
denp	Agglomerate Density, gm/cm^3
diflm	Diffusion Limit, amps/gm
eta	Agglomerate Polarization, volts
etaa	Anode Polarization, volts
etae	Collector Polarization, volts
ezero	Open Circuit Cell Voltage, volts
ghl	Cell Height, cm
gamal	Target Efficiency (External Input)
gama	Target Efficiency (Calculated)
gdel	Increment in Cell Height
ghlo	Initial Value of Cell Height, cm
grpow	Gross Power, watts
hmp	Impeller Height, cm
hdel	Increment in Impeller Height
hmpo	Initial Value Impeller Height
Gmax, kmax, lmax, mmax, nmax	Maximum Iteration Index
phi	Power Number, dimensionless
ptz	Catalyst Loading, gm/cm^3
plos	Parasitic Power Loss, watts

Nomenclature (cont'd)

qrad	Radial Pumping Rate, cm^3/sec
rec	Reynolds Number
rps	Speed, rps
rdel	Increment in Speed
rpso	Initial Value of Speed, rps
theta	Residence Time, sec
visso	Electrolyte Viscosity, poise
viss	Slurry Velocity, poise
volts	Cell Voltage, volts
wird	Collector Wire Diameter, cm
xj, xk, xl, xm, xx	Iteration Number (Floating Point)
xkapa	Dimensionless Parameter in Lagmuir and Bladget Equation
xnepow	Net Power Output, watts

APPENDIX III-1 (Cont'd)

SLURRY FUEL CELL - MODEL THREE (MECHANICAL)

```
101. =        ct     program okren6
102. =        c      slurry fuel cell - model three (mechanical)
103. =            0dimension rps(30),theta(30),xtm(30),amp(30),amps(30),afso(30),volt
                   1s(30),grpow(30),rec(30),phi(30),plos(30),xnepow(30),grad(30),dmp(3
                  40),hmp(30),celd(30),ghl(30),vell(30)
104. =            5 print 155
105. =             read 101,jmax,kmax,lmax,mmax,nmax,code
106. =            read 102,etaa,etae,gama1,as,ptz,diflm,eta
107. =             read 103,dens,viso,rho,thk,capac,ezero
108. =             read 104,rpso,hmpo,dmpo,celdo,ghlo
109. =              read 105,rdel,hdel,ddel,cdel,gdel
110. =              read 14,wird,denp,dp
111. =         14 format(3f10.6)
112. =        c      cgs units throughout
113. =             do 199 j=1,jmax
114. =             xj=j
115. =              dmp(j)=dmpo*(1.0+ddel*(xj-1.0))
116. =            do 199 k=1,kmax
117.=              xk=k
118. =              hmp(k)=hmpo*(1.0+hdel*(xk-1.0))
119. =            1 do 199 l=1,lmax
120. =              xl=l
121. =           25 celd(l)=celdo*(1.0+cdel*(xl-1.0))
122. =          170 do 199 m=1,mmax
123. =              xm=m
124. =           26 ghl(m)=ghlo*(1.0+gdel*(xm-1.0))
125. =           90 do 198 n=1,nmax
126. =              xn=n
127. =              rps(n)=rpso*(1.0+rdel*(xn-1.0))
128. =        c      power generator
129. =              if(capac-1.0)10,10,11
130. =           10 capak=13.4*exp(133.0*etae**2.9)
131. =              theto=2.24e4
132. =              go to 111
133. =           11 capak=capac
134. =              timk1=8.25e-6/(0.0138*capak)
135. =              go to 112
136. =          111 timk=theto*exp(133.0*etae**2.9)
137. =          112 timk1=1.0/timk
138. =              0viss=viso*(1.0+0.833*ptz+3.50*ptz**2+0.0625*exp(0.625*ptz/(1.0-0.5
                   431*ptz)))
139. =              grad(n)=rps(n)*hmp(k)*(3.1416*dmp(j))**2
140.=             if(gama1)175,175,30
141. =            30 gama=gama1
142. =             go to 174
143.=          175 area=3.1416*celd(l)*hmp(k)*(0.685*celd(l)/dmp(j)+0.315)
144. =              vell(n)=grad(n)/area
145. =              xkapa=0.222*denp*dp**2.9*vell(n)/(viss*wird)
146. =              if(xkapa-0.125)179,179,178
147. =          179 xnepow(n)=0.00
148. =              go to 198
149. =          178 if(xkapa-1.1)176,176,177
```

APPENDIX III-1 (CONT'D)

SLURRY FUEL CELL - MODEL THREE (MECHANICAL)

```
150. =        176 beth=8.0*xkapa
151. =            aleph=alog10(beth)
152. =            gama=0.466*aleph**2
153. =           go to 174
154. =        177 gama=xkapa/(xkapa+1.5709)
155. =       1740theta(n)=1.0/(3.1416*gama*as)*(ghl(m)/(rps(n)*hmp(k)))*(celd(l)/(2
               4.0*dmp(j)))**2
156. =            if(diflm-1.0)12,12,13
157. =         12 xtm(n)=1.0+timkl*theta(n)*exp(72.46*etae)
158. =            go to 131
159. =        130xtm(n)=72.46*(eta-etae)*8.25e-6/diflm+timkl*theta(n)*exp(72.46*eta
               4e)+1.0
160. =        131 amp(n)=0.0138*capak*grad(n)*gama*as*ptz
161. =            amps(n)=amp(n)*alog(xtm(n))
162. =            afsq(n)=amps(n)/(3.1416*celd(l)*hmp(k))
163. =            volts(n)=ezero-(etae+etaa+afsq(n)*rho)
164. =            grpow(n)=volts(n)*amps(n)
165. =           afsq(n)=afsq(n)*1000.0
166. =      c     power loss calculations
167. =            rec(n)=dens*rps(n)*dmp(j)**2/viss
168. =            if(rec(n)-20.0)135,135,140
169. =        135 phi(n)=70.0/rec(n)**1.183
170. =            go to 161
171. =        140 if(rec(n)-1000.0)141,141,150
172.=        141 phi(n)=4.0
173. =           go to 161
174. =        150 if(rec(n)-10000.0)151,151,160
175. =        151 phi(n)=5.0
176. =            go to 161
177. =        160 phi(n)=6.0
178. =        161 plos(n)=phi(n)*dens*rps(n)**3*dmp(j)**5*10.0e-7
179. =            xnepow(n)=grpow(n)-plos(n)
180. =       198 continue
181. =        23 do 195 n=1,nmax
182. =           if(n-nmax)21,17,17
183. =        21 if(xnepow(n))195,195,22
184. =         22 deln=xnepow(n+1)-xnepow(n)
185. =           if(deln)17,17,195
186. =        17 nm=n
187. =           xnm=nm
188. =       195 continue
189. =            do 199 n=1,nm
190. =            if(xnepow(n))199,199,16
191. =         16 if(code)19,19,18
192. =         18 print 115
193. =            print 110,dmp(j),hmp(k),celd(l),ghl(m),xnm,rps(n)
194. =            print 109
195. =           print 108
196. =           0print 107,grad(n),theta(n),amps(n),volts(n),grpow(n),afsq(n),plos(
               4n),xnepow(n)
197. =            go to 199
198. =        190print 106,dmp(j),hmp(k),celd(l),ghl(m),theta(n),rps(n),amps(n),vol
               4ts(n),plos(n),xnepow(n)
199. =        199 continue
200. =        101 format(6i4)
201. =        102 format(7f10.5)
202. =        103 format(6f10.5)
203. =        104 format(5f10.5)
204. =        105 format(5f10.5)
205. =        1060format(4x,f4.1,7x,f4.1,2(8x,f4.1),5x,f7.4,4x,f10.5,f10.5,5x,f10.5,
               4f10.5,3x,f10.5)
206. =        1070format(5x,f10.2,3x,f10.5,3x,f10.2,3x,f10.5,3x,f10.2,3x,f10.2,3x,f1
               40.3,3x,f10.2)
207. =        1080format(104h          grad        theta          amps          volts
               4   grpow        afsq          plos          xnepow   )
208. =        109 format(19h calculated results)
209. =        1150format(69h          dmp          hmp          celd          ghl
               4 xnm       rps)
210. =        110 format(4x,f4.1,7x,f4.1,3(8x,f4.1),4x,f10.5)
211. =        155 format(1h1,38x,43hslurry fuel cell - model three (mechanical))
212. =           stop
213. =           end
214. +ready
```

APPENDIX III-2

SLURRY FUEL CELL - MODEL THREE (MECHANICAL)

Input Data (See Program)

```
 1   1    1   1  30  -1
 0.0        0.200      0.00       0.752      0.100      0.00       0.07
 1.514      0.014      0.153      0.050      0.0        1.17
 1.00      10.00       7.64       8.00      15.24
 1.0       0.0        0.0       0.0        0.0
0.0188     3.00       0.001
```

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
7.6	10.0	8.0	15.2	40.1774	3.00000	8.51379	0.96482	6.38422	1.83004
7.6	10.0	8.0	15.2	2.8941	4.00000	73.47529	0.92527	15.13296	52.85157
7.6	10.0	8.0	15.2	0.9823	5.00000	163.41323	0.87052	29.55656	112.69785
7.6	10.0	8.0	15.2	0.4958	6.00000	259.30851	0.81214	51.07374	159.52152
7.6	10.0	8.0	15.2	0.3014	7.00000	352.60629	0.75535	81.10320	185.23626
7.6	10.0	8.0	15.2	0.2041	8.00000	439.38957	0.70251	121.06368	187.61385
7.6	10.0	8.0	15.2	0.1433	9.00000	518.12401	0.65458	172.37387	166.78161
7.6	10.0	8.0	15.2	0.1132	10.00000	588.53044	0.61172	236.45249	123.56485
7.6	10.0	8.0	15.2	0.0896	11.00000	650.97083	0.57371	314.71827	58.75082

Input Data (See Program)

```
 1   1    1   1  30  -1
 0.0        0.200      0.00       0.752      0.100      0.00       0.07
 1.514      0.014      0.153      0.050      0.0        1.17
 1.00      10.00       5.08       5.44      15.24
 1.0       0.0        0.0       0.0        0.0
0.0188     3.00       0.001
```

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
5.1	10.0	5.4	15.2	11.1957	5.00000	11.52408	0.95968	3.84154	7.21792
5.1	10.0	5.4	15.2	2.4779	6.00000	38.27034	0.93574	6.63819	29.17285
5.1	10.0	5.4	15.2	1.0687	7.00000	71.18881	0.90627	10.54119	53.97499
5.1	10.0	5.4	15.2	0.5968	8.00000	106.23831	0.87489	15.73496	77.21196
5.1	10.0	5.4	15.2	0.3826	9.00000	141.19159	0.84369	22.40388	96.70520
5.1	10.0	5.4	15.2	0.2674	10.00000	174.79618	0.81351	30.73234	111.46692
5.1	10.0	5.4	15.2	0.1982	11.00000	206.38153	0.78524	40.90475	121.15389
5.1	10.0	5.4	15.2	0.1533	12.00000	235.63592	0.75905	53.10549	125.75354
5.1	10.0	5.4	15.2	0.1225	13.00000	262.46900	0.73505	67.51806	125.40260
5.1	10.0	5.4	15.2	0.1004	14.00000	286.92384	0.71313	84.32955	120.28531
5.1	10.0	5.4	15.2	0.0840	15.00000	309.12012	0.69326	103.72166	110.57055
5.1	10.0	5.4	15.2	0.0714	16.00000	329.21748	0.67527	125.87968	96.43097
5.1	10.0	5.4	15.2	0.0616	17.00000	347.39228	0.65900	150.98800	77.94316
5.1	10.0	5.4	15.2	0.0537	18.00000	363.82322	0.64429	179.23102	55.17638
5.1	10.0	5.4	15.2	0.0474	19.00000	378.68279	0.63099	210.79314	28.15052

APPENDIX III-2 (CONT'D)

SLURRY FUEL CELL - MODEL THREE (MECHANICAL)

Input Data (See Program)

0.0	0.200	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	9.7386	3.00000	35.36934	0.95086	11.80890	21.82241
8.6	10.0	9.0	15.2	1.6530	4.00000	141.99605	0.89316	27.99148	98.83404
8.6	10.0	9.0	15.2	0.6683	5.00000	269.61724	0.82410	54.67085	167.52159
8.6	10.0	9.0	15.2	0.3644	6.00000	398.18618	0.75453	94.47123	205.97270
8.6	10.0	9.0	15.2	0.2315	7.00000	519.02117	0.68914	150.01681	207.66371
8.6	10.0	9.0	15.2	0.1614	8.00000	628.66567	0.62981	223.93180	172.00998
8.6	10.0	9.0	15.2	0.1197	9.00000	726.25641	0.57700	318.84040	100.21253

Input Data (See Program)

0.0	0.200	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	6.64	7.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.00	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
6.6	10.0	7.0	15.2	7.2519	4.00000	27.20168	0.95107	7.50408	18.36676
6.6	10.0	7.0	15.2	1.7106	5.00000	83.74807	0.91173	14.65641	61.69953
6.6	10.0	7.0	15.2	0.7557	6.00000	150.06679	0.86559	25.32627	104.57058
6.6	10.0	7.0	15.2	0.4283	7.00000	217.93878	0.81837	40.21718	138.13799
6.6	10.0	7.0	15.2	0.2776	8.00000	283.27042	0.77292	60.03264	158.91258
6.6	10.0	7.0	15.2	0.1957	9.00000	344.08834	0.73061	85.47617	165.91699
6.6	10.0	7.0	15.2	0.1461	10.00000	399.59306	0.69199	117.25126	159.26314
6.6	10.0	7.0	15.2	0.1137	11.00000	449.64038	0.65717	156.06142	139.42894
6.6	10.0	7.0	15.2	0.0914	12.00000	494.44017	0.62600	202.61017	106.91023
6.6	10.0	7.0	15.2	0.0753	13.00000	534.37873	0.59822	257.60101	62.07246
6.6	10.0	7.0	15.2	0.0632	14.00000	569.91467	0.57349	321.73745	5.10386

Input Data (See Program)

0.0	0.200	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	10.16	10.52	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.00	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
10.2	10.0	10.5	15.2	3.4931	3.00000	109.81437	0.91016	26.55274	74.38451
10.2	10.0	10.5	15.2	0.9462	4.00000	290.10953	0.83570	62.03984	179.50373
10.2	10.0	10.5	15.2	0.4414	5.00000	482.93475	0.74643	122.92937	237.54768
10.2	10.0	10.5	15.2	0.2534	6.00000	666.64018	0.66139	212.42196	228.48421
10.2	10.0	10.5	15.2	0.1714	7.00000	833.00980	0.58437	337.31819	149.46471
10.2	10.0	10.5	15.2	0.1230	8.00000	979.87048	0.51638	503.51870	2.46549

APPENDIX III-2 (CONT'D)

SLURRY FUEL CELL - MODEL THREE (MECHANICAL)

Input Data (See Program)

0.0	0.200	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	12.70	13.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.00	0.001				

Impeller Diameter cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
12.7	10.0	13.1	15.2	14.0729	2.00000	54.97436	0.94950	24.00964	28.18850
12.7	10.0	13.1	15.2	1.4493	3.00000	329.37339	0.84718	81.03255	198.00444
12.7	10.0	13.1	15.2	0.5311	4.00000	661.01151	0.72351	192.07715	286.16863
12.7	10.0	13.1	15.2	0.2792	5.00000	982.60591	0.60358	375.15068	217.93261

Input Data (See Program)

0.0	0.200	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	15.25	15.60	15.25		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.00	0.001				

Impeller Diameter, cm	Impeller Height cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
15.2	10.0	15.6	15.2	4.6519	2.00000	192.91697	0.90977	59.93994	115.57083
15.2	10.0	15.6	15.2	0.8661	3.00000	678.97488	0.75803	202.29731	312.38759
15.2	10.0	15.6	15.2	0.3647	4.00000	196.54695	0.59645	479.51954	234.16403

Input Data (See Program)

0.0	0.200	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	7.64	8.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.00	0.0005				

Input Data (See Program)

0.0	0.200	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	15.25	15.60	15.25		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.00	0.0005				

APPENDIX III-2 (CONT'D)

SLURRY FUEL CELL - MODEL THREE (MECHANICAL)

Input Data (See Program)

0.0	0.175	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	9.7386	3.00000	17.66721	0.98544	11.80890	5.60106
8.6	10.0	9.0	15.2	1.6530	4.00000	61.10772	0.96103	27.99148	30.79006
8.6	10.0	9.0	15.2	0.6683	5.00000	102.16477	0.93972	54.67085	41.33502
8.6	10.0	9.0	15.2	0.3044	6.00000	135.04934	0.92192	94.47123	30.03364

Input Data (See Program)

0.0	0.250	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	9.7386	3.00000	160.02127	0.83341	11.80890	121.55417
8.6	10.0	9.0	15.2	1.6530	4.00000	733.61950	0.52302	27.99148	355.70601
8.6	10.0	9.0	15.2	0.6683	5.00000	550.99606	0.08072	54.67085	70.51999

Input Data (See Program)

0.0	0.300	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	9.7386	3.00000	51.52951	0.30039	11.80890	304.69151

Input Data (See Program)

0.0	0.200	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	5.000	8.64	9.00	10.04		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	5.0	9.0	10.0	12.8315	3.00000	18.56743	0.94991	11.80890	5.82840
8.6	5.0	9.0	10.0	2.1780	4.00000	76.10987	0.88763	27.99148	39.56593
8.6	5.0	9.0	10.0	0.8806	5.00000	147.08010	0.81082	54.67085	64.58499
8.6	5.0	9.0	10.0	0.4802	6.00000	220.70752	0.73114	94.47123	66.89665
8.6	5.0	9.0	10.0	0.3051	7.00000	291.91656	0.65407	150.01681	40.91792

APPENDIX III-2 (CONT'D)

SLURRY FUEL CELL - MODEL THREE (MECHANICAL)

Input Data (See Program)

0.0	0.185	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	5.000	8.64	9.00	10.04		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Input Data (See Program)

0.0	0.185	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, Volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	9.7386	3.00000	23.33164	0.97237	11.80890	10.87819
8.6	10.0	9.0	15.2	1.6530	4.00000	86.63095	0.93812	27.99148	53.28693
8.6	10.0	9.0	15.2	0.6683	5.00000	153.87285	0.90174	54.67085	84.08175
8.6	10.0	9.0	15.2	0.3644	6.00000	214.00495	0.86915	94.47123	91.60891
8.6	10.0	9.0	15.2	0.2315	7.00000	264.68548	0.84177	150.01681	72.78709
8.6	10.0	9.0	15.2	0.1614	8.00000	306.04649	0.81939	223.93180	26.83975

Input Data (See Program)

0.0	0.225	0.00	0.752	0.100	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, Volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	9.7386	3.00000	72.72174	0.90555	11.80890	54.05143
8.6	10.0	9.0	15.2	1.6530	4.00000	317.11008	0.77340	27.99148	217.26803
8.6	10.0	9.0	15.2	0.6683	5.00000	644.81943	0.59607	54.67085	329.68779
8.6	10.0	9.0	15.2	0.3644	6.00000	913.09946	0.39679	94.47123	307.51245

Input Data (See Program)

0.0	0.200	0.00	0.752	0.200	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, Volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	54.9845	3.00000	16.46044	0.96109	11.80890	4.01111
8.6	10.0	9.0	15.2	3.1494	4.00000	174.22448	0.87572	27.99148	124.58085
8.6	10.0	9.0	15.2	1.0336	5.00000	399.04053	0.75407	54.67085	246.23323
8.6	10.0	9.0	15.2	0.5146	6.00000	640.81767	0.62324	94.47123	304.91017
8.6	10.0	9.0	15.2	0.3195	7.00000	877.08710	0.49539	150.01681	284.47964

APPENDIX III-2 (CONT'D)

SLURRY FUEL CELL - MODEL THREE (MECHANICAL)

Input Data (See Program)

0.0	0.200	0.00	0.752	0.300	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, Volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	10.1000	4.00000	102.98643	0.91427	27.99148	66.16607
8.6	10.0	9.0	15.2	2.0096	5.00000	368.26247	0.77072	54.67085	229.15779
8.6	10.0	9.0	15.2	0.8428	6.00000	690.45200	0.59638	94.47123	317.29989

Input Data (See Program)

0.0	0.200	0.00	0.752	0.400	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, Volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	5.9335	5.00000	211.41945	0.85560	54.67085	126.21869
8.6	10.0	9.0	15.2	1.7033	6.00000	555.52230	0.66939	94.47123	277.39133
8.6	10.0	9.0	15.2	0.8020	7.00000	952.71173	0.45446	150.01681	282.95575
8.6	10.0	9.0	15.2	0.4682	8.00000	361.89104	0.23305	223.93180	93.45142

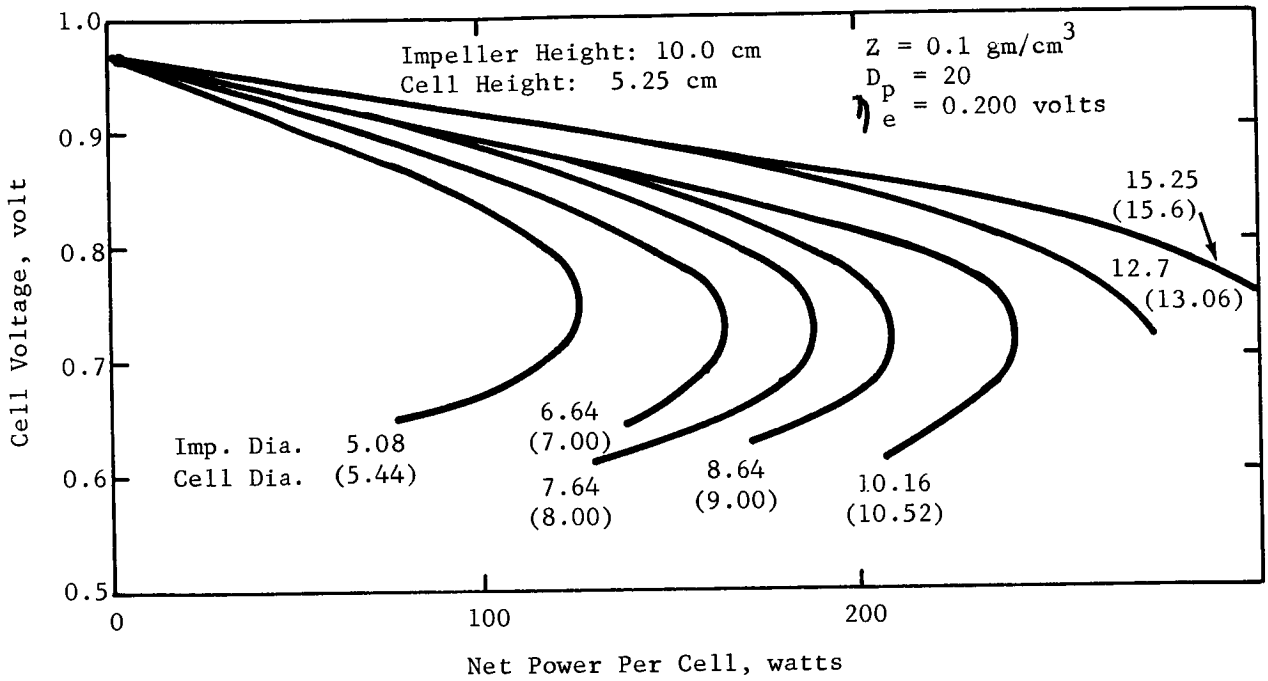
Input Data (See Program)

0.0	0.200	0.00	0.752	0.05	0.00	0.07
1.514	0.014	0.153	0.050	0.0	1.17	
1.00	10.00	8.64	9.00	15.24		
1.0	0.0	0.0	0.0	0.0		
0.0188	3.0	0.001				

Impeller Diameter, cm	Impeller Height, cm	Cell Diameter, cm	Cell Height, cm	θ_r, sec	Speed, rps	Current, amps	Cell Voltage, Volts	Parasitic Loss, Watts	Net Power Output, watts/cm
8.6	10.0	9.0	15.2	6.3989	3.00000	24.87203	0.95654	11.80890	11.98221
8.6	10.0	9.0	15.2	1.3388	4.00000	82.86258	0.92516	27.99148	48.66974
8.6	10.0	9.0	15.2	0.5740	5.00000	149.16765	0.88928	54.67085	77.98119
8.6	10.0	9.0	15.2	0.3220	6.00000	214.57228	0.85389	94.47123	88.74978
8.6	10.0	9.0	15.2	0.2080	7.00000	275.21831	0.82107	150.01681	75.95733
8.6	10.0	9.0	15.2	0.1466	8.00000	329.70984	0.79159	223.93180	37.06175

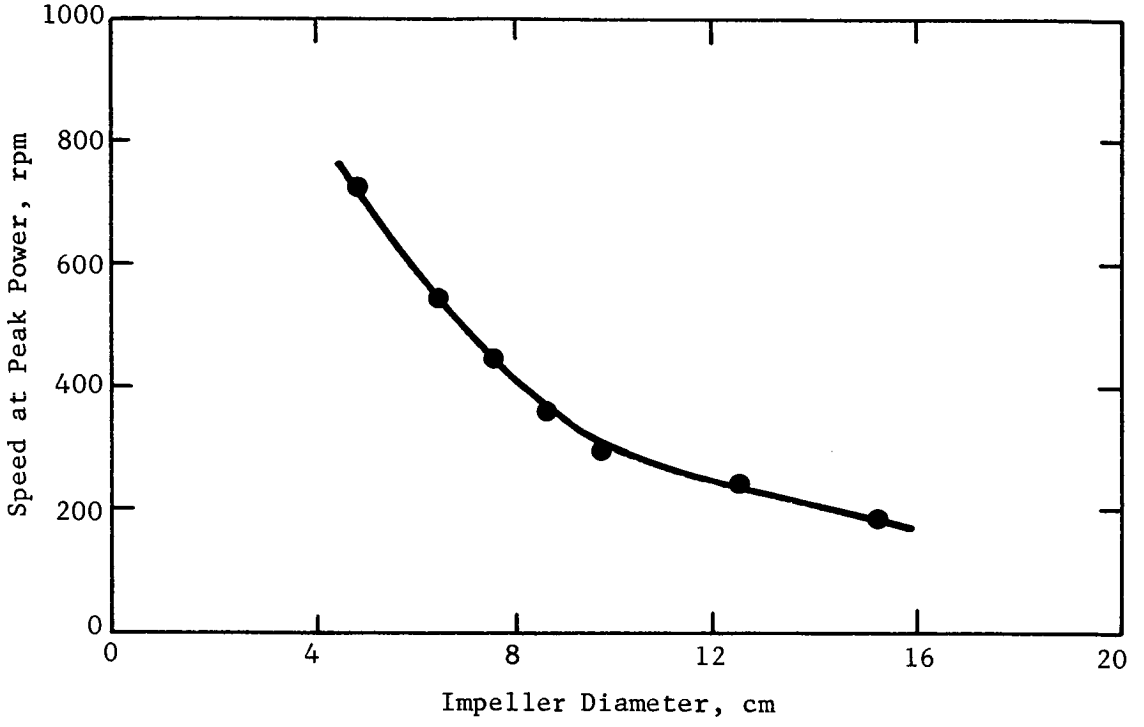
APPENDIX III-3

EFFECT OF IMPELLER DIAMETER ON POWER OUTPUT



APPENDIX III-4

EFFECT OF IMPELLER DIAMETER ON PEAK POWER SPEED



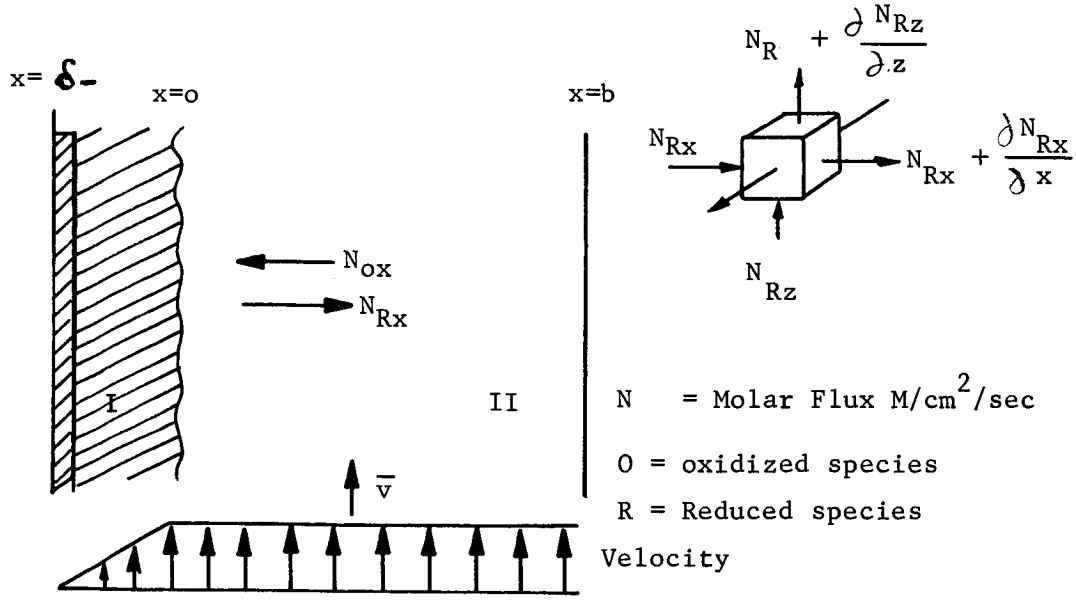
APPENDIX IV-1

CATHODE CHAMBER MASS TRANSPORT ANALYSIS CATHODE MEDIATOR FUEL CELL

The mass transport analysis of the cathode chamber of the mediator fuel cell is analogeous to that encountered in other soluble fuel or redox couple systems. The oxidized mediator is transported to the cathode chamber with the flowing electrolyte. It diffuses to the catalytic cathode where it is reduced, and the reduced mediator couple then diffuses back to the bulk electrolyte to be transported out of the chamber for re-oxidation. The solution developed in this analysis assumes that two zones exist in the chamber, a diffusion boundry zone of thickness δ and a plug flow region of thickness b. The approach then is to solve for the concentration at x=o from which the required electrode surface concentrations may be calculated. This is illustrated in Figure IV-1.

Figure IV-1

Cathode Chamber Mass Transport Model



In the forced convection mass transport zone the liquid velocity is assumed to be uniform (plug flow). Thus, a material balance on the oxidized and reduced species is

$$\frac{\partial N_{ox}}{\partial x} + \frac{\partial N_{oy}}{\partial_y} + \frac{\partial N_{oz}}{\partial_z} = o$$

$$\frac{\partial N_{Rx}}{\partial x} + \frac{\partial N_{Ry}}{\partial y} + \frac{\partial N_{Rz}}{\partial z} = o \qquad \text{(IV-1)}$$

but no diffusion or reaction is occurring in the y direction so that

$$\frac{\partial N_{ox}}{\partial_x} + \frac{\partial N_{oz}}{\partial_z} = o$$

$$\frac{\partial N_{Rx}}{\partial_x} + \frac{\partial N_{Rz}}{\partial_z} = o \qquad \text{(IV-2)}$$

The flux equations in the x and directions may now be written:

<u>For The X Direction</u>

$$N_{ox} = - C D_o \frac{\partial X}{\partial x} + X \left[N_{ox} + N_{Rx}\right]$$

$$N_{Rx} = - C D_r \frac{\partial Y}{\partial x} + Y \left[N_{ox} + N_{Rx}\right] \qquad \text{(IV-3a)}$$

<u>For the Z Direction</u>

$$N_{oz} = - C D_o \frac{\partial X}{\partial z} + X \left[N_{oz} + N_{Rz}\right]$$

$$N_{Rz} = - C D_t \frac{\partial Y}{\partial z} + Y \left[N_{oz} + N_{Rz}\right] \qquad \text{(IV-3b)}$$

where C is the total molar concentration and X and Y are the appropriate mole fractions. It it is assumed that mass transport in the Z direction occurs by convection only, while transport in the x direction occurs solely by diffusion, Equation IV-3 can be simplified to yield

$$N_{ox} = - C D_o \frac{\partial X}{\partial x}, \quad N_{Rx} = - C D_r \frac{\partial Y}{\partial x}$$

$$N_{oz} = C X V_z \qquad N_{Rz} = CYV_z \qquad \text{(IV-4)}$$

(The Equations for the reduced species are identical and will not be carried beyond this point. However, they will be used in the final η_c calculation)

Substitution of Equation IV-4 into Equation IV-2 yields the following differential equation,

$$v_z \frac{\partial X}{\partial z} = D_o \frac{\partial^2 X}{\partial_x^2} \qquad \text{(IV-5)}$$

which must be solved for the following boundry conditions:

$$\begin{array}{lll} z = o & o < x < b & X = X_o \\ o < z < L & x = o & \left.\frac{\partial X}{\partial x}\right|_o = -\frac{N_{ox}}{cD_o} \end{array} \qquad \text{(IV-5a)}$$

The latter boundary condition assumes a constant flux at the edge of the mass transport boundary layer. Equation IV-5 can be solved using the method of Pigford. The resulting equation for change in mole fraction.*

$$X - X_o = \left[\frac{N_{ox}}{cD_o}\right]\left[\frac{\pi D_o z}{v_z}\right]^{\frac{1}{2}} \left[1 - \text{erf}\ \frac{x}{2\left(\frac{D_o}{v_z} z\right)^{\frac{1}{2}}}\right]$$

can be evaluated at x=o such that

$$X_{x=o} - X_o = \frac{N_{ox}}{CD_o}\left(\frac{\pi D_o Z}{v_z}\right)^{\frac{1}{2}} \qquad \text{(IV-6)}$$

Applying the mean value theorem, the average concentration at the edge of the boundry layer is

$$X_{x=o} - X_o = \frac{2}{3}\left(\frac{N_{ox}}{CD_o}\right)\left(\frac{\pi D_o h}{v_z}\right)^{\frac{1}{2}} \qquad \text{(IV-7)}$$

Multiplying equation IV-7 by C (remembering that $CX = C_{ox}$ and $-N_{ox} = \frac{I}{2F}$) yields

$$\left[C_{ox}\right]_o - \left[C_{ox}\right]_{x=o} = \left(\frac{I}{3FD_o}\right)\left(\frac{\pi D_o h}{v_z}\right)^{\frac{1}{2}} \qquad \text{(IV-8)}$$

but $\frac{I}{2F} = \frac{D_o}{\delta}\left(\left[C_{ox}\right]_{x=o} - \left[C_{ox}\right]_{\delta-}\right)$,

or $$\left[C_{ox}\right]_{\delta-} = \left[C_{ox}\right]_{x=o} - \frac{I\delta}{2FD_o} \qquad \text{(IV-9)}$$

---

* Alternate form can be found in Carslaw and Yaeger for reverse concentration profiles.

The concentration of oxidized species at the electrode can be determined by substituting Equation IV-8 into IV-9,

$$\left[C_{ox}\right]_{\delta-} = \left[C_{ox}\right]_o - \frac{I}{2FD_o}\left[\delta + \frac{2}{3}\left(\frac{\pi D_o h}{v_z}\right)^{\frac{1}{2}}\right] \qquad \text{(IV-10)}$$

Similarly the reduced species concentration at the electrode can be calculated,

$$\left[C_{rD}\right]_{\delta-} = \left[C_{rD}\right]_o + \frac{I}{2FD_r}\left[\delta + \frac{2}{3}\left(\frac{\pi D_r h}{v_z}\right)^{\frac{1}{2}}\right] \qquad \text{(IV-11)}$$

The altered sign is due to the flux direction. Inserting these concentrations into Equation 24, Section IV, gives the electrode polarization

$$\eta_c = \frac{RT}{2F} \text{ Ln } \left[\frac{\left[1 + \frac{I}{2FD_r\left[C_{rd}\right]_o}\left(\delta + \frac{2}{3}\left(\frac{\pi D_r h}{v_z}\right)^{\frac{1}{2}}\right)\right]}{\left[1 - \frac{I}{2FD_o\left[C_{ox}\right]_o}\left(\delta + \frac{2}{3}\left(\frac{\pi D_o h}{v_z}\right)^{\frac{1}{2}}\right)\right]}\right] \qquad \text{(IV-12)}$$

in terms of concentration, velocity and boundry layer thickness. Since D_o is assumed equal to D_r these subscripts will be dropped.

The solution to the boundry value problem required to establish the concentration boundry thickness is given in Bird Steward and Lightfoot, "Transport Phenomena", pages 605 to 608. Their solution for the case of no chemical reaction in the boundry film is

$$\frac{\delta}{\delta_H} = \left(\frac{\rho D}{\mu}\right)^{\frac{1}{3}} \quad \text{where } \delta \text{ is the} \qquad \text{(IV-13)}$$

Concentration boundry layer thickness and δ_H is the hydrodynamic boundary layer thickness. Using the hydrodynamic boundry layer equation in Schlichting "Boundary-layer Theory" the concentration boundry layer thickness for use in Equation IV-12 is

$$\delta = 0.52\left(\frac{\mu z}{\rho v_z}\right)^{\frac{1}{2}}\left(\frac{\rho D}{\mu}\right)^{1/3} \quad \text{(cgs units)} \qquad \text{(IV-14)}$$

Again, averaging over the cell height introduces a factor of 0.667 so that

$$\delta = 0.347\left(\frac{\mu h}{\rho v_z}\right)^{\frac{1}{2}}\left(\frac{\rho D}{\mu}\right)^{1/3} \qquad \text{(IV-15)}$$

Incorporating the δ value into Equation IV-12 and introducing a more convenient set of concentration terms results in Equation 25 of Section IV.

APPENDIX IV-2

MEDIATOR FUEL CELL - CELL DESIGN

Nomenclature

nvell	velocity iteration index
ncode	current density iteration index
ncase	case number
etaa	anode polarization, volts
flow	flow rate step size (cm^3/sec/cell)
a	cathode chamber thickness, cm
w	cathode chamber width, cm
h	cathode chamber height, cm
viss	catholyte viscosity, poise
dens	catholyte density, gm/cm^3
dif	mediator diffusivity, cm^2/sec
amp	current density step size, ma/cm^2
t	cell temperature, °C
thk	matrix thickness, cm (not used)
rho	matrix resistance, ohm cm^2
xmol	mediator concentration moles/lt
xin	fraction of oxidized mediator at inlet to cell
vell	catholyte velocity, cm/sec
amps	current density, ma/cm^2
alim	limiting current density, ma/cm^2
etao	open current cathode polarization, volts
etae	cathode polarization, volts
volts	cell volts, volts
grpow	gross power output, watts

Internal Formula Names

delc, anum, dnum

APPENDIX IV-2 (Cont'd)

MEDIATOR FUEL CELL - CELL DESIGN

```
101. =        cf     program okren4
102. =        c      mediator fuel cell / part one cell design
103. =              0dimension flow1(30),vell(30),delc(30),alim(30),amps(15,15),anum(15
                    4,15),dnum(15,15),etac(15,15),etae(15,15),volts(15,15),grpow(15,15)
104. =            4 read 5,kount
105. =            5 format(79x,i1)
106. =              if(kount-1)9,10,9
107. =            9 if(kount-9)8,190,190
108. =            8 print 18
109. =           18 format(23h data card is incorrect)
110. =              go to 4
111. =           10 read 1,nvell,ncode,ncase,etaa
112. =              read 2,flow,a,w,h,viss,dens,dif
113. =              read 3,amp,t,thk,rho,xmol,xin
114. =              read 5,kount2
115. =              if(kount2-2)15,16,15
116. =           15 print 17
117. =           17 format(17h input data error)
118. =              go to 4
119. =           16 do 160 i=1,nvell
120. =              xi=i
121. =              flow1(i)=flow*xi
122. =              vell(i)=flow1(i)/(a*w)
123. =              delc(i)=0.347*(dens*dif/viss)**0.333*(viss*h/(dens*vell(i)))**0.50
124. =        c     xmol = mols/ht, amps = miliamps/cm2, x mols ox med. / mol. med,
125. =        c     t - deg. cent
126. =              0alim(i)=dif*xmol*xin/(5.18e-6*(delc(i)+1.182*(dif*h/vell(i))**0.50
                    4))
127. =              do 150 j=1,ncode
128. =              xj=j
129. =              amps(i,j)=amp*xj
130. =              delta=alim(i)-amps(i,j)
131. =              if(delta)20,20,21
132. =
133. =           20 print 170,alim(i)
134. =              go to 150
135. =          210anum(i,j)=1.0+5.18e-6*amps(i,j)/(dif*xmol*(1.0-xin))*(delc(i)+1.18
                    42*(dif*h/vell(i))**0.50)
136. =              0dnum(i,j)=1.0-5.18e-6*amps(i,j)/(dif*xmol*xin)*(delc(i)+1.182*(dif
                    4*h/vell(i))**0.50)
137. =              etac(i,j)=4.293e-5*(t+273.0)*alog(anum(i,j)/dnum(i,j))
138. =              etao=0.2774-(0.00014*t+4.293e-5*(t+273.0)*alog(xin/(1.0-xin)))
139. =              etae(i,j)=etac(i,j)+etao
140. =              tvolt=1.249*(1.0-0.0008*t)
141. =              volts(i,j)=tvolt-(etaa+etae(i,j)+rho*amps(i,j)*0.001)
142. =              grpow(i,j)=amps(i,j)*volts(i,j)*h*w*0.001
143. =          150 continue
144. =              print 171,t,tvolt,ncase,etao
145. =              print 175
146. =              print 172,flow1(i),(amps(i,j),j=1,15)
147. =              print 176
148. =              print 173,flow1(i),(volts(i,j),j=1,15)
149. =              print 177
150. =              print 174,flow1(i),(grpow(i,j),j=1,15)
151. =          170 format(18h limiting current=,  f6.2,7h ma/cm2)
152. =          171 format(2f8.4,i5,f8.4)
153. =          172 format(f6.1,15f6.0/)
154. =          173 format(f6.1,15f6.3/)
155. =          174 format(f6.1,15f7.1)
156. =            1 format(3i5,f10.5)
157. =            2 format(6f10.5,f10.8)
158. =            3 format(6f10.5)
159. =          175 format(23h current density ma/cm2)
160. =          176 format(20h cell voltage, volts)
161. =          177 format(38h gross power, watts-one third ft2 cell)
162. =          160 continue
163. =              go to 4
164. =          190 stop
165. =              end
166. +ready         purge[okren4]
166. +ready
```

APPENDIX IV-3

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
166. +ready        start[0]
104. =i 05                                                                                  1
111. =i 01      15    15     1    0.0
112. =i 02     10.0        0.20       22.86       14.60       0.014       1.514    .00001
113. =i 03     25.0       95.0         0.050       0.15       0.500       0.90
114. =i 05                                                                                  2
133. =o170    limiting current= 46.89 ma/cm2
144. =o171    95.0000  1.1541     1  0.2294
145. =o175    current density ma/cm2
146. =o172     10.0    25.    50.    -0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     10.0 0.881 0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     10.0     7.4     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
133. =o170    limiting current= 66.31 ma/cm2
144. =o171    95.0000  1.1541     1  0.2294
145. =o175    current density ma/cm2
146. =o172     20.0    25.    50.    75.     0.     0.     0.     0.     0.    -0.    -0.     0.     0.     0.     0.    -0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     20.0 0.890 0.863 0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     20.0     7.4    14.4     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
133. =o170    limiting current= 81.22 ma/cm2
144. =o171    95.0000  1.1541     1  0.2294
145. =o175    current density ma/cm2
146. =o172     30.0    25.    50.    75.   100.    -0.     0.    -0.    -0.     0.     0.    -0.     0.     0.     0.     0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     30.0 0.894 0.872 0.838 0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     30.0     7.5    14.6    21.0     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
133. =o170    limiting current= 93.78 ma/cm2
144. =o171    95.0000  1.1541     1  0.2294
145. =o175    current density ma/cm2
146. =o172     40.0    25.    50.    75.   100.    -0.     0.     0.     0.     0.     0.     0.     0.     0.    -0.     0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     40.0 0.897 0.877 0.855 0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     40.0     7.5    14.6    21.4     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
133. =o170    limiting current=104.85 ma/cm2
144. =o171    95.0000  1.1541     1  0.2294
145. =o175    current density ma/cm2
146. =o172     50.0    25.    50.    75.   100.   125.     0.     0.     0.     0.    -0.     0.     0.     0.     0.     0.
146. =     2
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
147. =o176   cell voltage, volts
148. =o173    50.0 0.899 0.881 0.862 0.825 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    50.0    7.5   14.7   21.6   27.5    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=114.86 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172    60.0   25.   50.   75.  100.  125.    0.    0.    0.   -0.    0.    0.    0.    0.   -0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173    60.0 0.900 0.883 0.866 0.843 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    60.0    7.5   14.7   21.7   28.1    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=124.06 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172    70.0   25.   50.   75.  100.  125.    0.   -0.   -0.    0.    0.    0.    0.    0.    0.   -0.
146. =     2
147. =o176   cell voltage, volts
148. =o173    70.0 0.901 0.885 0.869 0.850 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    70.0    7.5   14.8   21.8   28.4    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=132.63 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172    80.0   25.   50.   75.  100.  125.  150.   -0.    0.   -0.    0.    0.    0.   -0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173    80.0 0.902 0.886 0.872 0.855 0.825 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    80.0    7.5   14.8   21.8   28.5   34.4    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=140.67 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172    90.0   25.   50.   75.  100.  125.  150.   -0.    0.    0.    0.    0.   -0.    0.   -0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173    90.0 0.903 0.888 0.874 0.858 0.837 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    90.0    7.5   14.8   21.9   28.7   34.9    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=148.28 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172   100.0   25.   50.   75.  100.  125.  150.    0.    0.   -0.    0.    0.    0.   -0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   100.0 0.903 0.889 0.875 0.861 0.843 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   100.0    7.5   14.8   21.9   28.7   35.2    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=155.52 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172   110.0   25.   50.   75.  100.  125.  150.  175.    0.    0.   -0.   -0.   -0.    0.    0.    0.
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
146. =    2
147. =o176   cell voltage, volts
148. =o173   110.0 0.904 0.890 0.877 0.863 0.847 0.814 0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   110.0    7.5   14.8   21.9   28.8   35.3   40.7    0.0    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=162.44 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172   120.0   25.   50.   75.  100.  125.  150.  175.    0.    0.    0.    0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   120.0 0.905 0.890 0.878 0.865 0.850 0.826 0.000 0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   120.0    7.5   14.9   22.0   28.9   35.5   41.4    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=169.07 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172   130.0   25.   50.   75.  100.  125.  150.  175.    0.    0.   -0.   -0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   130.0 0.905 0.891 0.879 0.866 0.853 0.833 0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   130.0    7.6   14.9   22.0   28.9   35.6   41.7    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=175.45 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172   140.0   25.   50.   75.  100.  125.  150.  175.  200.    0.    0.    0.    0.    0.    0.   -0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   140.0 0.905 0.892 0.880 0.868 0.855 0.838 0.768 0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   140.0    7.6   14.9   22.0   29.0   35.7   41.9   44.9    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=181.61 ma/cm2
144. =o171   95.0000  1.1541    1  0.2294
145. =o175   current density ma/cm2
146. =o172   150.0   25.   50.   75.  100.  125.  150.  175.  200.   -0.    0.    0.    0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   150.0 0.906 0.892 0.881 0.869 0.856 0.841 0.810 0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   150.0    7.6   14.9   22.0   29.0   35.7   42.1   47.3    0.     0.     0.     0.     0.     0.     0.     0.
104. =i 05        start[0]
108. =o 18   data card is incorrect
104. =i 05                                                                                                  1
111. =i 01     15   15    2   0.0
112. =i 02    10.0       0.20      22.86      14.60      0.014      1.514   .00001
113. =i 03    25.0      95.0       0.050      0.150      1.000      0.90
114. =i 05                                                                                                  2
133. =o170   limiting current= 93.78 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172    10.0   25.   50.   75.  100.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
148. =o173    10.0 0.897 0.877 0.855 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    10.0    7.5   14.6   21.4    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=132.63 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172    20.0   25.   50.   75.  100.  125.  150.    0.    0.   -0.   -0.    0.    0.    0.    0.   -0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    20.0 0.902 0.886 0.872 0.855 0.825 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    20.0    7.5   14.8   21.8   28.5   34.4    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=162.44 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172    30.0   25.   50.   75.  100.  125.  150.  175.   -0.    0.    0.   -0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    30.0 0.905 0.890 0.878 0.865 0.850 0.826 0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    30.0    7.5   14.9   22.0   28.9   35.5   41.4    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=187.57 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172    40.0   25.   50.   75.  100.  125.  150.  175.  200.    0.    0.    0.    0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    40.0 0.906 0.893 0.881 0.870 0.858 0.844 0.820 0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    40.0    7.6   14.9   22.1   29.0   35.8   42.2   47.9    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=209.71 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172    50.0   25.   50.   75.  100.  125.  150.  175.  200.  225.   -0.    0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    50.0 0.907 0.895 0.884 0.873 0.862 0.851 0.836 0.810 0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    50.0    7.6   14.9   22.1   29.1   36.0   42.6   48.8   54.1    0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=229.72 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172    60.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.    0.    0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    60.0 0.908 0.896 0.886 0.875 0.865 0.855 0.843 0.828 0.793 0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    60.0    7.6   15.0   22.2   29.2   36.1   42.8   49.2   55.3   59.6    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=248.13 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172    70.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.    0.    0.    0.    0.   -0.
146. =    2
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
147. =o176   cell voltage, volts
148. =o173    70.0 0.909 0.897 0.887 0.877 0.868 0.858 0.848 0.835 0.818 0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    70.0    7.6   15.0   22.2   29.3   36.2   43.0   49.5   55.8   61.5    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=265.26 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172    80.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.    0.   -0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    80.0 0.910 0.898 0.888 0.879 0.870 0.860 0.851 0.840 0.827 0.807 0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    80.0    7.6   15.0   22.2   29.3   36.3   43.1   49.7   56.1   62.1   67.3    0.     0.     0.     0.     0.
133. =o170   limiting current=281.35 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172    90.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    90.0 0.910 0.899 0.889 0.880 0.871 0.862 0.853 0.843 0.832 0.818 0.787 0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    90.0    7.6   15.0   22.3   29.4   36.3   43.2   49.8   56.3   62.5   68.2   72.3    0.     0.     0.     0.
133. =o170   limiting current=296.57 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172   100.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.   -0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   100.0 0.911 0.900 0.890 0.881 0.873 0.864 0.855 0.846 0.836 0.824 0.807 0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   100.0    7.6   15.0   22.3   29.4   36.4   43.3   50.0   56.5   62.8   68.8   74.0    0.     0.     0.     0.
133. =o170   limiting current=311.04 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172   110.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   110.0 0.911 0.900 0.891 0.882 0.874 0.865 0.857 0.848 0.839 0.828 0.815 0.791 0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   110.0    7.6   15.0   22.3   29.4   36.4   43.3   50.0   56.6   63.0   69.1   74.8   79.2    0.     0.     0.
133. =o170   limiting current=324.87 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172   120.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   120.0 0.911 0.901 0.892 0.883 0.875 0.866 0.858 0.850 0.841 0.831 0.820 0.804 0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   120.0    7.6   15.0   22.3   29.5   36.5   43.4   50.1   56.7   63.2   69.4   75.2   80.5    0.     0.     0.
133. =o170   limiting current=338.14 ma/cm2
144. =o171   95.0000  1.1541    2  0.2294
145. =o175   current density ma/cm2
146. =o172   130.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.  350.    0.
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
146. =     2
147. =o176    cell voltage, volts
148. =o173    130.0 0.912 0.901 0.892 0.884 0.876 0.868 0.860 0.851 0.843 0.834 0.823 0.811 0.789 0.    0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174    130.0    7.6    15.0    22.3    29.5    36.5    43.4    50.2    56.8    63.3    69.6    75.6    81.2    85.6    0.      0.
133. =o170    limiting current=350.90 ma/cm2
144. =o171    95.0000  1.1541    2  0.2294
145. =o175    current density ma/cm2
146. =o172    140.0    25.    50.    75.   100.   125.   150.   175.   200.   225.   250.   275.   300.   325.   350.   375.
146. =     2
147. =o176    cell voltage, volts
148. =o173    140.0 0.912 0.902 0.893 0.884 0.876 0.868 0.861 0.853 0.845 0.836 0.826 0.815 0.799 0.742 0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174    140.0    7.6    15.0    22.3    29.5    36.6    43.5    50.3    56.9    63.4    69.7    75.8    81.6    86.7    86.6    0.
133. =o170    limiting current=363.22 ma/cm2
144. =o171    95.0000  1.1541    2  0.2294
145. =o175    current density ma/cm2
146. =o172    150.0    25.    50.    75.   100.   125.   150.   175.   200.   225.   250.   275.   300.   325.   350.   375.
146. =     2
147. =o176    cell voltage, volts
148. =o173    150.0 0.912 0.902 0.893 0.885 0.877 0.869 0.862 0.854 0.846 0.838 0.829 0.818 0.806 0.784 0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174    150.0    7.6    15.1    22.4    29.5    36.6    43.5    50.3    57.0    63.5    69.9    76.1    81.9    87.4    91.6    0.
150. =break   150.
166. +ready
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
148. =break  148.
166. +ready       start[0]
104. =i 05                                                                                  1
111. =i 01     15    15     2    0.0
112. =i 02    30.0        0.20      22.86      14.60       0.014      1.514    .00001
113. =i 03    50.0       40.0        0.050      0.150      1.000      0.90
114. =i 05                                                                                  2
133. =o170   limiting current=162.44 ma/cm2
144. =o171   40.0000  1.2090     2  0.2423
145. =o175   current density ma/cm2
146. =o172    30.0   50.  100.  150.  200.    0.     0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    30.0 0.936 0.914 0.880 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    30.0   15.6   30.5   44.0   30.5   37.6   44.0    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=229.72 ma/cm2
144. =o171   40.0000  1.2090     2  0.2423
145. =o175   current density ma/cm2
146. =o172    60.0   50.  100.  150.  200.  250.    0.    0.    0.     0.            0.    0.    0.    0.   -0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    60.0 0.941 0.923 0.904 0.880 0.    0.                            0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    60.0   15.7   30.8   45.3   58.7   38.1   45.3   52.2   58.7   63.8    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=281.35 ma/cm2
144. =o171   40.0000  1.2090     2  0.2423
145. =o175   current density ma/cm2
146. =o172    90.0   50.  100.  150.  200.  250.  300.  175.   -0.    0.    0.   -0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    90.0 0.944 0.927 0.910 0.893 0.870 0.880 0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    90.0   15.7   30.9   45.6   59.6   72.6   44.0    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=324.87 ma/cm2
144. =o171   40.0000  1.2090     2  0.2423
145. =o175   current density ma/cm2
146. =o172   120.0   50.  100.  150.  200.  250.  300.  350.   0.     0.    0.    0.    0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   120.0 0.945 0.929 0.914 0.899 0.882 0.857   0.   0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   120.0   15.8   31.0   45.8   60.0   73.6   85.8   51.1    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=363.22 ma/cm2
144. =o171   40.0000  1.2090     2  0.2423
145. =o175   current density ma/cm2
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
146. =o172   150.0   50.  100.  150.  200.  250.  300.  350.  400.   0.     -0.    0.    0.    0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   150.0 0.946 0.931 0.916 0.902 0.887 0.870 0.839   0.   0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   150.0   15.8   31.1   45.9   60.2   74.0   87.1   98.0   57.7    0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=397.89 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   180.0   50.  100.  150.  200.  250.  300.  350.  400.   0.    0.      0.    0.    0.   -0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   180.0 0.947 0.932 0.918 0.904 0.890 0.875 0.856   0.   0.   0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   180.0   15.8   31.1   46.0   60.4   74.3   87.6  100.0   58.7   63.8    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=429.77 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   210.0   50.  100.  150.  200.  250.  300.  350.  400.  450.    0.    0.    0.    0.    0.   -0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   210.0 0.948 0.933 0.919 0.906 0.893 0.879 0.863 0.841    0.       0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   210.0   15.8   31.1   46.0   60.5   74.5   88.0  100.8  112.2   65.4    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=459.44 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   240.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.   0.     0.   -0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   240.0 0.949 0.934 0.921 0.908 0.895 0.882 0.867 0.850 0.816   0.   0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   240.0   15.8   31.2   46.1   60.6   74.7   88.3  101.3  113.5  122.6   71.8    0.     0.     0.     0.     0.
133. =o170   limiting current=487.31 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   270.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.   0.    0.      0.   -0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   270.0 0.949 0.935 0.921 0.909 0.896 0.884 0.870 0.855 0.835   0.   0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   270.0   15.8   31.2   46.1   60.7   74.8   88.5  101.7  114.2  125.4    0.     0.       0.     0.     0.     0.

133. =o170   limiting current=513.67 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   300.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.   0.    -0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   300.0 0.949 0.935 0.922 0.910 0.898 0.885 0.872 0.859 0.842 0.812   0.   0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   300.0   15.8   31.2   46.2   60.7   74.9   88.6  101.9  114.6    0.     0.     79.0    0.     0.     0.     0.
133. =o170   limiting current=538.74 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
145. =o175   current density ma/cm2
146. =o172   330.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.  300.  325.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   330.0 0.950 0.936 0.923 0.911 0.899 0.887 0.874 0.861 0.846 0.826 0.867 0.846 0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   330.0   15.8   31.2   46.2   60.8   75.0   88.8  102.1  115.0  127.1  137.9   79.6   84.7    0.     0.     0.
133. =o170   limiting current=562.70 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   360.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.  600.   0.     0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   360.0 0.950 0.936 0.924 0.912 0.900 0.888 0.876 0.863 0.849 0.833 0.803   0.   0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   360.0   15.9   31.2   46.2   60.8   75.1   88.9  102.3  115.2  127.6  139.0  147.3   85.8    0.     0.     0.
133. =o170   limiting current=585.68 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   390.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.  600.    0.   0.     0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   390.0 0.950 0.937 0.924 0.912 0.901 0.889 0.877 0.865 0.852 0.837 0.816   0.    0.   0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   390.0   15.9   31.3   46.3   60.9   75.1   89.0  102.5  115.5  127.9  139.7  149.9   86.4   91.5    0.     0.
133. =o170   limiting current=607.79 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   420.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.  600.  650.   0.     0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   420.0 0.951 0.937 0.925 0.913 0.901 0.890 0.878 0.866 0.854 0.840 0.823 0.787    0.      0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   420.0   15.9   31.3   46.3   60.9   75.2   89.1  102.6  115.7  128.2  140.2  151.1  157.7   92.5   93.8    0.
133. =o170   limiting current=629.12 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   450.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.  600.  650.   0.     0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   450.0 0.951 0.937 0.925 0.913 0.902 0.891 0.879 0.868 0.855 0.842 0.827 0.805   0.    0.   0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   450.0   15.9   31.3   46.3   61.0   75.3   89.2  102.7  115.8  128.5  140.6  151.8  161.2   0.      0.    0.
104. =i 05        start[0]
108. =o 18   data card is incorrect
104. =i 05                                                                                                  1
111. =i 01     15   15    2   0.0
112. =i 02    50.0       40.0        0.050      0.150      1.000      0.90
113. =i 03                                                                                                  2
114. =i 05                                                                                                  1
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
106. +ready        start[0]
104. =i 05                                                                                  1
111. =i 01      15    15     1    0.0
112. =i 02     10.0        0.20      22.86      14.60      0.014      1.514    .00001
113. =i 03     25.0       60.0        0.050      0.150     1.000      0.90
114. =i 05                                                                                  2
133. =o170    limiting current= 93.78 ma/cm2
144. =o171    60.0000  1.1890    1  0.2376
145. =o175    current density ma/cm2
146. =o172     10.0   25.   50.   75.  100.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     10.0 0.926 0.908 0.887 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     10.0    7.7   15.2   22.2    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170    limiting current=132.63 ma/cm2
144. =o171    60.0000  1.1890    1  0.2376
145. =o175    current density ma/cm2
146. =o172     20.0   25.   50.   75.  100.  125.  150.    0.    0.   -0.   -0.    0.    0.    0.    0.   -0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     20.0 0.931 0.916 0.902 0.887 0.860 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     20.0    7.8   15.3   22.6   29.6   35.9    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170    limiting current=162.44 ma/cm2
144. =o171    60.0000  1.1890    1  0.2376
145. =o175    current density ma/cm2
146. =o172     30.0   25.   50.   75.  100.  125.  150.  175.   -0.    0.    0.   -0.    0.    0.    0.    0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     30.0 0.933 0.920 0.908 0.896 0.882 0.860 0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     30.0    7.8   15.3   22.7   29.9   36.8   43.1    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170    limiting current=187.57 ma/cm2
144. =o171    60.0000  1.1890    1  0.2376
145. =o175    current density ma/cm2
146. =o172     40.0   25.   50.   75.  100.  125.  150.  175.  200.    0.    0.    0.    0.    0.   -0.    0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     40.0 0.934 0.922 0.911 0.900 0.889 0.876 0.855 0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     40.0    7.8   15.4   22.8   30.1   37.1   43.9   49.9    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170    limiting current=209.71 ma/cm2
144. =o171    60.0000  1.1890    1  0.2376
145. =o175    current density ma/cm2
146. =o172     50.0   25.   50.   75.  100.  125.  150.  175.  200.  225.   -0.    0.    0.    0.    0.    0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     50.0 0.935 0.924 0.913 0.903 0.893 0.882 0.869 0.845 0.    0.    0.    0.    0.    0.    0.
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    50.0    7.8   15.4   22.9   30.2   37.3   44.2   50.7   56.4    0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=229.72 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172    60.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.    0.    0.    0.   -0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173    60.0 0.936 0.925 0.915 0.906 0.896 0.886 0.875 0.861 0.830 0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    60.0    7.8   15.4   22.9   30.2   37.4   44.4   51.1   57.5   62.3    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=248.13 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172    70.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.    0.    0.    0.    0.   -0.
146. =     2
147. =o176   cell voltage, volts
148. =o173    70.0 0.937 0.926 0.916 0.907 0.898 0.889 0.879 0.868 0.852 0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    70.0    7.8   15.5   22.9   30.3   37.5   44.5   51.4   57.9   64.0    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=265.26 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172    80.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.    0.   -0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173    80.0 0.938 0.927 0.917 0.909 0.900 0.891 0.882 0.872 0.860 0.841 0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    80.0    7.8   15.5   23.0   30.3   37.5   44.6   51.5   58.2   64.6   70.2    0.     0.     0.     0.     0.
133. =o170   limiting current=281.35 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172    90.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.    0.   -0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173    90.0 0.938 0.928 0.918 0.910 0.901 0.893 0.884 0.875 0.865 0.851 0.823 0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    90.0    7.8   15.5   23.0   30.4   37.6   44.7   51.7   58.4   64.9   71.0   75.6    0.     0.     0.     0.
133. =o170   limiting current=296.57 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172   100.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.   -0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   100.0 0.938 0.928 0.919 0.911 0.902 0.894 0.886 0.877 0.868 0.857 0.841 0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   100.0    7.8   15.5   23.0   30.4   37.7   44.8   51.8   58.6   65.2   71.5   77.2    0.     0.     0.     0.
133. =o170   limiting current=311.04 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172   110.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.    0.    0.
146. =     2
147. =o176   cell voltage, volts
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
148. =o173   110.0 0.939 0.929 0.920 0.911 0.903 0.896 0.888 0.879 0.871 0.861 0.848 0.826 0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   110.0    7.8   15.5   23.0   30.4   37.7   44.8   51.8   58.7   65.4   71.8   77.8   82.7    0.     0.     0.
133. =o170   limiting current=324.87 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172   120.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   120.0 0.939 0.929 0.920 0.912 0.904 0.897 0.889 0.881 0.873 0.863 0.853 0.838 0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   120.0    7.8   15.5   23.0   30.4   37.7   44.9   51.9   58.8   65.5   72.0   78.3   83.9    0.     0.     0.
133. =o170   limiting current=338.14 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172   130.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.  350.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   130.0 0.939 0.930 0.921 0.913 0.905 0.898 0.890 0.882 0.874 0.866 0.856 0.844 0.824 0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   130.0    7.8   15.5   23.1   30.5   37.8   44.9   52.0   58.9   65.7   72.2   78.6   84.5   89.4    0.     0.
133. =o170   limiting current=350.90 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172   140.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.  350.  375.
146. =    2
147. =o176   cell voltage, volts
148. =o173   140.0 0.940 0.930 0.921 0.913 0.906 0.898 0.891 0.883 0.876 0.868 0.858 0.848 0.834 0.781 0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   140.0    7.8   15.5   23.1   30.5   37.8   45.0   52.0   59.0   65.8   72.4   78.8   84.9   90.4   91.2    0.
133. =o170   limiting current=363.22 ma/cm2
144. =o171   60.0000  1.1890    1  0.2376
145. =o175   current density ma/cm2
146. =o172   150.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.  350.  375.
146. =    2
147. =o176   cell voltage, volts
148. =o173   150.0 0.940 0.930 0.922 0.914 0.907 0.899 0.892 0.885 0.877 0.869 0.861 0.851 0.839 0.819 0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   150.0    7.8   15.5   23.1   30.5   37.8   45.0   52.1   59.0   65.9   72.5   79.0   85.2   91.0   95.7    0.
104. =i 05                                                                                      1
111. =i 01     15   15    2   0.0
112. =i 02    10.0       0.20     22.86     14.60     0.014     1.514   .00001
113. =i 03    25.0      40.0       0.050     0.150     1.000     0.90
114. =i 05                                                                                      2
133. =o170   limiting current= 93.78 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172    10.0   25.   50.   75.  100.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    10.0 0.942 0.925 0.906 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    10.0    7.9   15.4   22.7    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
133. =o170   limiting current=132.63 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172    20.0   25.   50.   75.  100.  125.  150.    0.    0.   -0.   -0.    0.    0.    0.    0.   -0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    20.0 0.947 0.933 0.920 0.905 0.879 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    20.0    7.9   15.6   23.0   30.2   36.7    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=162.44 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172    30.0   25.   50.   75.  100.  125.  150.  175.   -0.    0.    0.   -0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    30.0 0.949 0.936 0.925 0.914 0.900 0.880 0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    30.0    7.9   15.6   23.2   30.5   37.6   44.0    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=187.57 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172    40.0   25.   50.   75.  100.  125.  150.  175.  200.    0.    0.    0.    0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    40.0 0.950 0.939 0.928 0.918 0.907 0.894 0.874 0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    40.0    7.9   15.7   23.2   30.6   37.8   44.8   51.1    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=209.71 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172    50.0   25.   50.   75.  100.  125.  150.  175.  200.  225.   -0.    0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    50.0 0.952 0.940 0.930 0.921 0.911 0.900 0.888 0.865 0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    50.0    7.9   15.7   23.3   30.7   38.0   45.1   51.8   57.7    0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=229.72 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172    60.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.    0.    0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    60.0 0.952 0.941 0.932 0.923 0.914 0.904 0.894 0.880 0.850 0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    60.0    7.9   15.7   23.3   30.8   38.1   45.3   52.2   58.7   63.8    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=248.13 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172    70.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.    0.    0.    0.    0.   -0.
146. =    2
147. =o176   ce-1 voltage, volts
148. =o173    70.0 0.953 0.942 0.933 0.924 0.916 0.907 0.897 0.886 0.871 0.    0.    0.    0.    0.    0.
-
146. =    2
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
                    147. =o176   cell voltage, volts
148. =o173    70.0 0.953 0.942 0.933 0.924 0.916 0.907 0.897 0.886 0.871 0.    0.    0.    -    -    0.    0.
-
146. =    2
147. =o176   cell voltage, volts
148. =o1-3    70.0 0.953 0.942 0.933 0.924 0.916 0.907 0.897 0.886 0.871 0.    0.    0.    0.    0.    0.
-
146. =    2
147. =o176   cell voltage, volts
148. =o173    70.0 0.953 0.942 0.933 0.924 0.916 0.907 0.897 0.886 0.871 0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    70.0    8.0   15.7   23.4   30.8   38.2   45.4   52.4   59.2   65.4    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=265.26 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172    80.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.    0.   -0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    80.0 0.953 0.943 0.934 0.926 0.917 0.909 0.900 0.890 0.879 0.861 0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    80.0    8.0   15.7   23.4   30.9   38.3   45.5   52.6   59.4   66.0   71.8    0.     0.     0.     0.     0.
133. =o170   limiting current=281.35 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172    90.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    90.0 0.954 0.944 0.935 0.927 0.918 0.910 0.902 0.893 0.883 0.870 0.844 0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    90.0    8.0   15.7   23.4   30.9   38.3   45.6   52.7   59.6   66.3   72.6   77.5    0.     0.     0.     0.
133. =o170   limiting current=296.57 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   100.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  2-5.  10-.   --.    0.    0.
-
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density mj/cm2--146. =o172   100.0-  25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.
 0.                                  .          0                                                                  0          -
-o171   40.0000  1.2090   -2  0.2423
145. =o175   current density ma/cm2
146. =o172   100.0   25.   50.   75.  102.  12-.  15-.  17m.  200.  225.  2-0.  275.  300.   -0. 1  0.    0.
-
144. =o171   40.0000  1.2090    2  0.2423
-w----o175   current densit- ma/c-2
146. =o172   100.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.   -0.    0.    0.
-146. =    2
147. =o176   cell voltage, volts
148.-=o17    10-ah0.954 0.944 0.936 0.927 0.920 0.912 0.904 0.895 0.886 0.875 0.860 0.    0.    0.    0.
-
146. =   -k-          -
147. =o176   cell voltage, volts
148. =o173   100.0 0.954 0.944 0.936 0.927 0.920 0.912 0.904 0.895 0.886 0.875 0.860 0.    0.    0     -    0.
-
146. =    2
147. =o176   cell voltage, volts
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
--
  -48. =r-+-   100.0 0.9-4 0.944 0.936 0;927 0.920 0.912 0.904 0.895 0.886 0.875 0.860 0.    0.    0.    0.
-
 46. =    2--
147. =o176   cell voltage, volts
148. =o173   100.0 0.954 0.944 0.936 0.927 0.920 0.912 0.904 0.895 0.886 0.87n-0.86--.   -   0.    0.
-148. =    2       -j
149--=o177 - gross po-er, watts-one third ft2 cell
150. =o174   100.0    8.0   15.8   23.4   31.0   38.4   45.6 - 52.8-- 59.--  66.-   73.0   79.0    0. -   0.     0.     0.
-
148. =    2
149. =o177   gross power, wxtts-one third ft2 cell
150. =-174   100.0    8.0   15.8   23.4   31.0   38.4   45.6   52.8   59.8   66.6   73.0   79.0    0.     0.     0.     0. -
-                                  -
148. =   -2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   100.0-'  8.0   15.-   23.4   31.0   38.4   45.6   52.8   59--  66.6   73.0   79.0    0.     0.     0.     0.
-
148. =    2       -
149. =o177   gross po-er, watts-one third ft2 cell
150. =o174   100.0    8.0   15.8   23.4   31.0   38.4   45.6   52.8   59.8   66.6 - 73.0-  79.-    0.     0.     0.   - 0.  -
-133. =o170   limyting -urrent=311.0--ma/cm2
-
133. =o170   limiting current=311.04 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   110.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   110.0 0.955 0.945 0.936 0.928 0.921 0.913 0.905 0.897 0.889 0.879 0.867 0.846 0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   110.0    8.0   15.8   23.4   31.0   38.4   45.7   52.9   59.9   66.7   73.3   79.6   84.7    0.     0.     0.
133. =o170   limiting current=324.87 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   120.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   120.0 0.955 0.945 0.937 0.929 0.921 0.914 0.906 0.899 0.891 0.882 0.871 0.857 0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   120.0    8.0   15.8   23.5   31.0   38.4   45.8   52.9   60.0   66.9   73.6   80.0   85.8    0.     0.     0.
133. =o170   limiting current=338.14 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   130.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.  350.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   130.0 0.955 0.946 0.937 0.930 0.922 0.915 0.907 0.900 0.892 0.884 0.874 0.863 0.844 0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   130.0    8.0   15.8   23.5   31.0   38.5   45.8   53.0   60.1   67.0   73.7   80.3   86.4   91.5    0.     0.
133. =o170   limiting current=350.90 ma/cm2
144. =o171   40.0000  1.2090    2  0.2423
145. =o175   current density ma/cm2
146. =o172   140.0   25.   50.   75.  100.  125.  150.  175.  200.  225.  250.  275.  300.  325.  350.  375.
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
166. +ready        start[0]
104. =i 05                                                                                  1
111. =i 01      15    15     1    0.0
112. =i 02     10.0        0.20      22.86      14.60       0.014      1.514    .00001
113. =i 03     25.0       40.0        0.050      0.15       0.500      0.90
114. =i 05                                                                                  2
133. =o170    limiting current= 46.89 ma/cm2
144. =o171    40.0000  1.2090     1  0.2423
145. =o175    current density ma/cm2
146. =o172     10.0    25.    50.    -0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     10.0 0.929 0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     10.0     7.8     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
133. =o170    limiting current= 66.31 ma/cm2
144. =o171    40.0000  1.2090     1  0.2423
145. =o175    current density ma/cm2
146. =o172     20.0    25.    50.    75.     0.     0.     0.     0.     0.    -0.    -0.     0.     0.     0.     0.    -0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     20.0 0.937 0.913 0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     20.0     7.8    15.2     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
133. =o170    limiting current= 81.22 ma/cm2
144. =o171    40.0000  1.2090     1  0.2423
145. =o175    current density ma/cm2
146. =o172     30.0    25.    50.    75.   100.    -0.     0.    -0.    -0.     0.     0.    -0.     0.     0.     0.     0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     30.0 0.940 0.921 0.891 0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     30.0     7.8    15.4    22.3     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
133. =o170    limiting current= 93.78 ma/cm2
144. =o171    40.0000  1.2090     1  0.2423
145. =o175    current density ma/cm2
146. =o172     40.0    25.    50.    75.   100.    -0.     0.     0.     0.     0.     0.     0.     0.     0.    -0.     0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     40.0 0.942 0.925 0.906 0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
148. =     2
149. =o177    gross power, watts-one third ft2 cell
150. =o174     40.0     7.9    15.4    22.7     0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.      0.
133. =o170    limiting current=104.85 ma/cm2
144. =o171    40.0000  1.2090     1  0.2423
145. =o175    current density ma/cm2
146. =o172     50.0    25.    50.    75.   100.   125.     0.     0.     0.     0.    -0.     0.     0.     0.     0.     0.
146. =     2
147. =o176    cell voltage, volts
148. =o173     50.0 0.944 0.928 0.912 0.880 0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
148. =     2
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
149. =o177   gross power, watts-one third ft2 cell
150. =o174    50.0    7.9   15.5   22.8   29.4    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=114.86 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172    60.0   25.   50.   75.  100.  125.    0.    0.    0.   -0.    0.    0.    0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    60.0 0.945 0.930 0.915 0.895 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    60.0    7.9   15.5   22.9   29.9    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=124.06 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172    70.0   25.   50.   75.  100.  125.    0.   -0.   -0.    0.    0.    0.    0.    0.    0.   -0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    70.0 0.946 0.932 0.918 0.901 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    70.0    7.9   15.5   23.0   30.1    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=132.63 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172    80.0   25.   50.   75.  100.  125.  150.   -0.    0.   -0.    0.    0.    0.   -0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    80.0 0.947 0.933 0.920 0.905 0.879 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    80.0    7.9   15.6   23.0   30.2   36.7    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=140.67 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172    90.0   25.   50.   75.  100.  125.  150.   -0.    0.    0.    0.    0.   -0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    90.0 0.948 0.934 0.922 0.908 0.889 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    90.0    7.9   15.6   23.1   30.3   37.1    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=148.28 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   100.0   25.   50.   75.  100.  125.  150.    0.    0.   -0.    0.    0.    0.   -0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   100.0 0.948 0.935 0.923 0.910 0.894 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   100.0    7.9   15.6   23.1   30.4   37.3    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=155.52 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   110.0   25.   50.   75.  100.  125.  150.  175.    0.    0.   -0.   -0.   -0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   110.0 0.949 0.936 0.924 0.912 0.898 0.869 0.    0.    0.    0.    0.    0.    0.    0.    0.
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   110.0    7.9   15.6   23.1   30.4   37.5   43.5    0.0    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=162.44 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   120.0   25.   50.   75.  100.  125.  150.  175.    0.    0.    0.    0.    0.    0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   120.0 0.949 0.936 0.925 0.914 0.900 0.880 0.000 0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   120.0    7.9   15.6   23.2   30.5   37.6   44.0    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=169.07 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   130.0   25.   50.   75.  100.  125.  150.  175.    0.    0.   -0.   -0.    0.    0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   130.0 0.949 0.937 0.926 0.915 0.903 0.885 0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   130.0    7.9   15.6   23.2   30.5   37.7   44.3    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=175.45 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   140.0   25.   50.   75.  100.  125.  150.  175.  200.    0.    0.    0.    0.    0.    0.   -0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   140.0 0.950 0.938 0.927 0.916 0.904 0.889 0.830 0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   140.0    7.9   15.6   23.2   30.6   37.7   44.5   48.4    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=181.61 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   150.0   25.   50.   75.  100.  125.  150.  175.  200.   -0.    0.    0.    0.    0.   -0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173   150.0 0.950 0.938 0.928 0.917 0.906 0.892 0.865 0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   150.0    7.9   15.7   23.2   30.6   37.8   44.7   50.6    0.     0.     0.     0.     0.     0.     0.     0.
104. =i 05                                                                                                  1
111. =i 01     15   15    1   0.0
112. =i 02     30.0       0.20      22.86      14.60      0.014      1.514   .00001
113. =i 03     50.0      40.0       0.050      0.150      1.000      0.90
114. =i 05                                                                                                  2
133. =o170   limiting current=162.44 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172    30.0   50.  100.  150.  200.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
146. =     2
147. =o176   cell voltage, volts
148. =o173    30.0 0.936 0.914 0.880 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =     2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    30.0   15.6   30.5   44.0    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=229.72 ma/cm2
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172    60.0   50.  100.  150.  200.  250.    0.    0.    0.   -0.   -0.    0.    0.    0.    0.   -0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    60.0 0.941 0.923 0.904 0.880 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    60.0   15.7   30.8   45.3   58.7    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=281.35 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172    90.0   50.  100.  150.  200.  250.  300.   -0.   -0.    0.    0.   -0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173    90.0 0.944 0.927 0.910 0.893 0.870 0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174    90.0   15.7   30.9   45.6   59.6   72.6    0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=324.87 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   120.0   50.  100.  150.  200.  250.  300.  350.    0.    0.    0.    0.    0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   120.0 0.945 0.929 0.914 0.899 0.882 0.857 0.    0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   120.0   15.8   31.0   45.8   60.0   73.6   85.8    0.     0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=363.22 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   150.0   50.  100.  150.  200.  250.  300.  350.  400.    0.   -0.    0.    0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   150.0 0.946 0.931 0.916 0.902 0.887 0.870 0.839 0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   150.0   15.8   31.1   45.9   60.2   74.0   87.1   98.0    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=397.89 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   180.0   50.  100.  150.  200.  250.  300.  350.  400.   -0.    0.    0.    0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   180.0 0.947 0.932 0.918 0.904 0.890 0.875 0.856 0.    0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   180.0   15.8   31.1   46.0   60.4   74.3   87.6  100.0    0.     0.     0.     0.     0.     0.     0.     0.
133. =o170   limiting current=429.77 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   210.0   50.  100.  150.  200.  250.  300.  350.  400.  450.    0.    0.    0.    0.    0.   -0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   210.0 0.948 0.933 0.919 0.906 0.893 0.879 0.863 0.841 0.    0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   210.0   15.8   31.1   46.0   60.5   74.5   88.0  100.8  112.2    0.     0.     0.     0.     0.     0.     0.
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
133. =o170   limiting current=459.44 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   240.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.    0.    0.   -0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   240.0 0.949 0.934 0.921 0.908 0.895 0.882 0.867 0.850 0.816 0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   240.0   15.8   31.2   46.1   60.6   74.7   88.3  101.3  113.5  122.6    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=487.31 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   270.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.    0.   -0.    0.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   270.0 0.949 0.935 0.921 0.909 0.896 0.884 0.870 0.855 0.835 0.    0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   270.0   15.8   31.2   46.1   60.7   74.8   88.5  101.7  114.2  125.4    0.     0.     0.     0.     0.     0.
133. =o170   limiting current=513.67 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   300.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.    0.   -0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   300.0 0.949 0.935 0.922 0.910 0.898 0.885 0.872 0.859 0.842 0.812 0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   300.0   15.8   31.2   46.2   60.7   74.9   88.6  101.9  114.6  126.4  135.6    0.     0.     0.     0.     0.
133. =o170   limiting current=538.74 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   330.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.   -0.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   330.0 0.950 0.936 0.923 0.911 0.899 0.887 0.874 0.861 0.846 0.826 0.    0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   330.0   15.8   31.2   46.2   60.8   75.0   88.8  102.1  115.0  127.1  137.9    0.     0.     0.     0.     0.
133. =o170   limiting current=562.70 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   360.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.  600.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   360.0 0.950 0.936 0.924 0.912 0.900 0.888 0.876 0.863 0.849 0.833 0.803 0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   360.0   15.9   31.2   46.2   60.8   75.1   88.9  102.3  115.2  127.6  139.0  147.3    0.     0.     0.     0.
133. =o170   limiting current=585.68 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   390.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.  600.    0.    0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   390.0 0.950 0.937 0.924 0.912 0.901 0.889 0.877 0.865 0.852 0.837 0.816 0.    0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
```

APPENDIX IV-3 (Cont'd)

CALCULATED RESULTS MEDIATOR CELL DESIGN

(See Appendix IV-2 for Key)

```
150. =o174   390.0   15.9   31.3   46.3   60.9   75.1   89.0  102.5  115.5  127.9  139.7  149.9    0.     0.     0.     0.
133. =o170   limiting current=607.79 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   420.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.  600.  650.    0.   -0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   420.0 0.951 0.937 0.925 0.913 0.901 0.890 0.878 0.866 0.854 0.840 0.823 0.787 0.    0.    0.
148. =    2
149. =o177   gross power, watts-one third ft2 cell
150. =o174   420.0   15.9   31.3   46.3   60.9   75.2   89.1  102.6  115.7  128.2  140.2  151.1  157.7    0.     0.     0.
133. =o170   limiting current=629.12 ma/cm2
144. =o171   40.0000  1.2090    1  0.2423
145. =o175   current density ma/cm2
146. =o172   450.0   50.  100.  150.  200.  250.  300.  350.  400.  450.  500.  550.  600.  650.   -0.    0.
146. =    2
147. =o176   cell voltage, volts
148. =o173   450.0 0.951 0.937 0.925 0.913 0.902 0.891 0.879 0.868 0.855 0.842 0.827 0.805 0.    0.    0.
6
148. =break  148.
166. +ready
```

APPENDIX IV-4

EFFECT OF TEMPERATURE

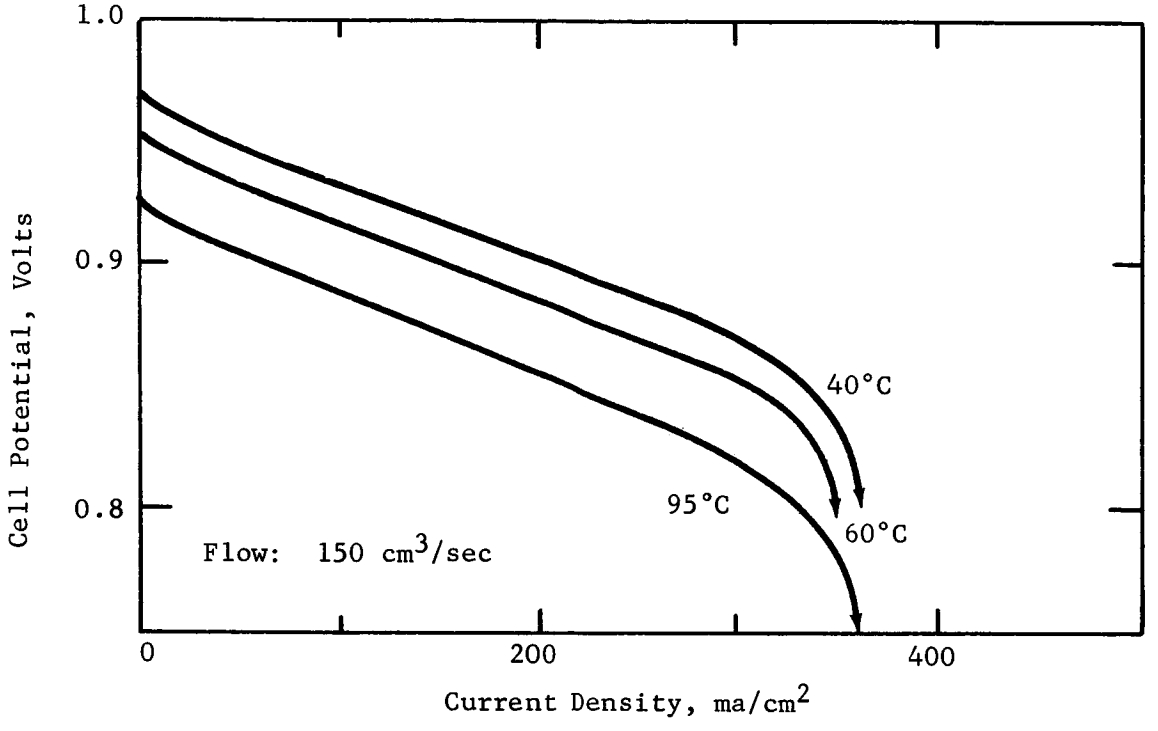
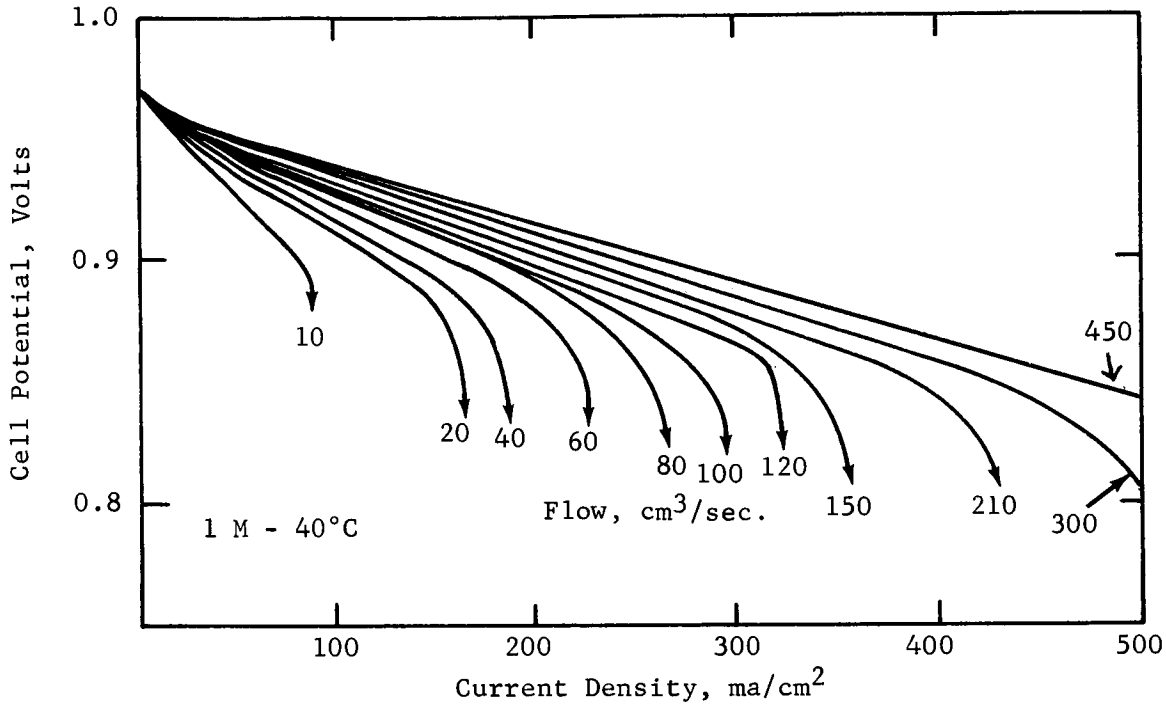


Figure IV-5

Performance of Mediator H_2-O_2 Fuel Cell



APPENDIX IV-6

SCRUBBER REGENERATOR DESIGN
MEDIATOR FUEL CELL

Part a - Absorption with Instantaneous Chemical Reaction

The oxygen absorption process occurring in the regenerator unit associated with the mediator fuel cell is distinguished by the fact that the mediator is undergoing an instantaneous reaction with the adsorbed oxygen. Thus, the concentration distribution of the (mediator) liquid phase reactant influences the overall absorption process especially at the high reactant concentrations (compared to O_2) encountered in this system. In addition, it was assumed that chemical reduction in the scrubber could not occur so that this reaction could be considered a "pseudo irreversible" reaction. Applying the penetration theory (Danckwert's Model)(*) to this case yields the following differential equations:

$$D_{O_2} \frac{\partial^2 c}{\partial x} = \frac{\partial c}{\partial t} \qquad x < \lambda \qquad \text{IV-16}$$

$$D_M \frac{\partial^2 b}{\partial x} = \frac{\partial b}{\partial t} \qquad x > \lambda \qquad \text{IV-16a}$$

where λ is the oxygen penetration depth, c is the oxygen concentration in solution and b is the reduced mediator concentration. The model assumes that under instantaneous reaction conditions both oxygen and reduced mediator cannot co-exist so that the reduced mediator concentration at film thickness less than λ is zero and conversely the oxygen concentration at values of film thickness greater than λ is also zero. That is $c \neq o$, $b = o$ and $c = o$, $b \neq o$. The resulting boundary conditions are

$t = o$	$c = o$	$b = bo$	IV-17a
$x = o$	$c = c_i$	(the interface concentration)	IV-17b
$x \rightarrow \infty$	$b = b_o$	(bulk reduced mediator concentration)	IV-17c
$x = \lambda$	$-\frac{1}{2} Do \frac{\partial C}{\partial x} = D_M \frac{\partial b}{\partial x}$	and $c = o$, $b = o$	IV-17d

Equation IV-17d simply satisfies the reaction stoichiometry at the plane of zero concentration. Obviously, the position of the reaction plane changes with time in accordance with Equation IV-18.

$$\frac{d\lambda}{dt} = -\left(\frac{\frac{\partial c}{\partial t}}{\frac{\partial c}{\partial x}}\right)_{x=\lambda} \qquad \text{(mass balance)} \qquad \text{IV-18}$$

(*) P. V. Danckwerts, Trans. Faraday Soc. 46 (1900) 701.

Applying the standard approximations used in moving boundry problems

$$C = C_L + A_1 \operatorname{erf}_2 \frac{x}{\sqrt{D_\theta t}} \qquad \text{IV-19}$$

$$b = b_o - A_2 \operatorname{erf}_2 \frac{x}{\sqrt{D_M t}} \qquad \text{IV-19a}$$

differentiating with respect to t and inserting the result into Equation IV-18 yields;

$$\frac{d\lambda}{dt} = \frac{\lambda}{t} \quad \text{or } \lambda = \sqrt{\alpha t} \quad .$$

A_1, A_2 and α are all integrating constants which can be evaluated by using boundry conditions IV-17d and Equation IV-18. Inserting these constants into Equations IV-19 and 19a, one obtains the instantaneous absorption rate

$$N\left(\frac{\text{moles}}{\text{cm}^2\,\text{sec}}\right) = -D_o \left.\frac{\partial c}{\partial x}\right|_{x=o} = \sqrt{\frac{D_{oz}}{\pi t}} \left(\frac{C_i}{\operatorname{erf}\sqrt{\frac{\alpha}{D_o}}}\right)$$

The $C_i\ (D_{oz}/\pi t)^{\frac{1}{2}}$ term is the physical absorption rate, so that the increased absorption is simply proportional to $(\operatorname{erf}\sqrt{\alpha}/D_o)^{-1}$ The final constant α may be evaluated using Equation IV-20.

$$\frac{C_i D_c^{\frac{1}{2}}}{2 \operatorname{erf}\sqrt{\frac{\alpha}{D_o}}} \exp\left(\frac{-\alpha}{D_o}\right) = \frac{b_o D_M^{\frac{1}{2}}}{\operatorname{erfc}\sqrt{\frac{\alpha}{D_M}}} \exp\left(\frac{-\alpha}{D_M}\right) \qquad \text{IV-20}$$

Considerable simplification is possible since the value of $b_o/z\ C_i$ is quite large since the solubility of O_2 in KOH is quite small. Under these conditions, the N. J. Sing (*) approximation applies,

$$\operatorname{erf}\sqrt{\frac{\alpha}{D_o}} \cong \sqrt{\frac{D_M}{D_o}} \operatorname{erf}\sqrt{\frac{\alpha}{D_M}} \ , \quad \exp\left(\frac{\alpha}{D_o} + \frac{\alpha}{D_M}\right) \cong 1$$

If D_c and D_M are not too dissimilar (as in this case) substitution in Equation IV-20 gives

$$\left(\operatorname{erf}\sqrt{\frac{\alpha}{D_o}}\right)^{-1} = \sqrt{\frac{D_o}{D_M}} + \sqrt{\frac{D_M}{D_o}}\ \frac{2b_o}{C_i} \quad \text{and}$$

*R. A. J. O. N. J. Sing, dissertation, Delft 1957.

the ratio of reaction enhanced absorption rate to physical absorption is simply.

$$\frac{k_L}{k_L^{\,o}} = \frac{1 + \frac{D_M}{D_o}\left(\frac{2b_o}{C_i}\right)}{\sqrt{D_M/D_o}} \qquad \text{IV-21}$$

Furthermore, if one assumes that the liquid phase diffusivities of O_2 and the mediator are identical this reduces to

$$\frac{k_1}{k_1^{\,o}} = 1 + \frac{2b_o}{C_i}\text{, and} \qquad \text{IV-21a}$$

the average absorption rate is simply

$$N = k_1^{\,o}\left[2bo + C_i\right] \qquad \text{IV-22}$$

where $k_L^{\,o}$ is the film coefficient for physical absorption.

Part b - Application to Packed Bed Scrubber Design

The procedure used to calculate the scrubber dimensions follows that proposed by Astarita* to evaluate the nature of the controlling process (physical or chemical absorption) since this can change along the length of the scrubber as the reaction proceeds. Furthermore, in applying Equation IV-22 to packed bed design, the gas phase resistance cannot always be neglected because the liquid side coefficients are greatly enhanced by the existence of the chemical reaction. Thus, the first step, in the scrubber analysis is evaluation of the conditions for the shift from "reaction" to physical absorption control. If k_g is the gas-phase mass transport coefficient (partial pressure inits) and P is the total pressure at a given interface, the absorption rate is given by

$$N = k_g\,(Py - HC_i) = k_L^{\,o}\,(2bo + C_i) \qquad \text{IV-23}$$

where y is the mole fraction of O_2, H is the Henry's law constant for O_2 in the electrolyte (atm-cm^3/g mole). Examination of Equation IV-23 indicates that when $k_g Py \geqslant 2k_1^o$ bo the reaction plane is located somewhere within the liquid phase (inner reaction controlling). If $k_g Py < 2k_1^o$ bo, the reaction takes place at the gas liquid interface, and the interface concentration of the mediator (b) drops to zero. This latter region is called the "Surface reaction" controlled region. Using these conditions it is now possible to design the required packed bed scrubber. In the following analysis, a co-current system was assumed for ease of phase separation under zero "g" conditions. However, both co-current and counter-current systems were analyzed and the difference in number of transfer units was found to be slight.

---

*Astarita, G., "Mass Transfer with Chemical Reaction" Elsevier Publishing Co., 1967, N. Y.

Turning to the packed tower shown in Figure 16 (Section IV) one can write the material balance equations for the various zones

Surface Control: $Gy - G_t Y_t = 2L_M \left[b - b_r\right]$ IV-24a

Inner Control: $G_b y_b - G_t = 2L_M \left[b_b - b\right]$ IV-24b

Overall: $G_b y_b - G_t y_t = 2L_M \left[b_b - b_t\right]$ IV-24c

where b represents the mole fraction of reduced mediator, and G represents the gas flow in g-moles/sec cm^2. At the point of transition between inner and surface controll the mole fraction of oxygen in the gas stream is

$$\left[y\right] = \frac{2K_L^o \left[b\right] M}{K_g \left[P\right]} \qquad \text{IV-25}$$

and the reduced mediator concentration at the transition zone can be shown to be

$$\left[b\right] = \frac{\left[\frac{G_b y_b}{2L_M} - b_b\right]}{\left[\frac{G_D K_L^o M}{P_b K_g L_M} - 1\right]} = \frac{\left(\frac{G_b y_b}{2L_M} - b_b\right)}{\left(\frac{H_g}{H_L} - 1\right)} \qquad \text{IV-26}$$

$$Hg = G/k_g a \ P \text{ and } H_L = L_M/MK_2 a$$

provided we assume that the tower operates at a constant gas velocity. For the inner reaction zone,

$$d(\theta) = d(2L_M (b_b - b) = K_L^o a \ (2bM + C_i) dh \qquad \text{IV-27}$$

where C_i may be evaluated using Equation IV-23,

$$C_i = \frac{Py - 2\frac{k_L^o}{k_g} Mb}{\left[\frac{k_L^o}{k_g} + H\right]} \qquad \text{IV-28}$$

Integrating Equation IV-27 and re-arranging terms one proceeds to solve for the inner zone scrubber height,

$$h_i = \left[\frac{H_{OL}}{\left(\frac{L_M P_b}{MHG_b} + 1\right)}\right] Ln \left[\frac{\left(\frac{P_b}{G_b}\right)\left(G_b y_b - 2L_M b_b\right) + 2\left[L_M \frac{P_b}{G_b} + MH\right] b_b}{\frac{P_b}{G_b}\left(G_b y_b - 2L_M b_b\right) + 2\left[L_M \frac{P_b}{G_b} + MH\right]\left[b\right]}\right] \qquad \text{IV-29}$$

remembering that $[b]$ is given by Equation IV-26. The height of the surface reaction zone is then readily determined,

$$h_s = \frac{L_M}{k_L{}^o aM} \int_{b_t}^{[b]} \frac{d_b}{b} = H_L \; L_n \left[\frac{b_b}{b_t} \left(\frac{\frac{G_b y_b}{2L_M b_b} - 1}{Hg/H_L - 1} \right) \right] \qquad \text{IV-30}$$

and the total lower height is simply $h_i + h_s$. The total cross-section is selected to set the liquid velocity at 60% of flooding velocity.

Pumping losses were determined using empirical equations for packed towers and scrubber weight was calculated from the weight of packing, liquid hold-up and shell weight assuming 100 mil wall thickness.

APPENDIX IV-7

MEDIATOR FUEL CELL - COMPLETE DESIGN

Nomenclature

	Same as in IV-2 plus the following
pb	scrubber inlet pressure, atm
wtp	weight percent KOH
ar	stoichiometric ratio (O_2)
ybtm	mole fraction O_2 entering
pc	cell pressure, atm
hlc	Heny's law content, atm cm^3/gm mole
abaro	packing sufface area percent volume ft^2/ft^3
eps	void fraction
apt	packing effectiveness factor, ft
pkden	packing density lb/ft^3
hkw	power level (design), kw
efic	pumping efficiency
toth	scrubber height, cm
wracl	scrubber weight, lbs
wpecl	stack weight, lbs
xauw	total weight, lbs
d	scrubber diameter, cm
xlbkw	specific power lb/kw
xnpow	net power output, kw
celn	number of cells
btop	mole fraction reduced mediator leaving scrubber
bbtm	mole fraction reduced mediator entering scrubber
deng	gas density, gm/cm^3
phi	flooding factor, dimensionless
area	tower cross sectional area per cell, cm^2
gblop	molar gas flow at exit, gm moles/ cm^2 sec
gbtm	molar gas flow at inlet gm moles/cm^2/sec
xlm	molar liquid flow rate, gm moles/cm^2 sec
gl, qg	weight rate of flow, liquid or a gas respectively, gm/sec
hl, hg	height of a transfer unit,liquid and gas respectively, cm
hol	overall height of a transfer unit, liquid, cm

APPENDIX IV-7 (CONT'D)

ht1	scrubber height, inner zone, cm
ht2	scrubber height, surface zone, cm
shwt	scrubber Shell weight, lbs
res	scrubber Reynolds number
theta	scrubber friction factor
al	flooding factor
scwl	parasitic power loss in scrubber
rec	cell Reynolds number
f	cell friction factor
cpl	cell parasitic power loss, watts
pumpl	total parasitic losses/watts
iopt	option code gas recirculation
noput	output suppression code
ntral	black box simulation code

APPENDIX IV-7 (Cont'd)

MEDIATOR FUEL CELL COMPLETE DESIGN

```
cf    program okren5
c     mediator fuel cell - complete design
c     all units cgs unless stated otherwise
c     options available - 1 iopt =1 gas recirculation included, = 0 gas
c     vented
c                         - 2 noput = 2 suppresses all but lb/kw data,
c                               = 0 prints all data
c                         - 3 ntral = 1 acts as black box system prints
c                         only one point, =0 no change in output sequence
      0dimension flow1(5),amps(5,5),volts(5,5),grpow(5,5),toth(5,5),wracl
      1(5,5),wpecl(5,5),xauw(5,5),d(5,5),xlbpkw(5,5),xnpow(5,5),alim(5),c
      4eln(5,5)

    4 read 5,kount
    5 format(79x,i1)
      if(kount-1)9,10,9
    9 if(kount-9)11,190,190
   11 print 18
   18 format(23h data card is incorrect)
      go to 4
   10 read 1,nvell,ncode,ncase,iopt,noput,ntral
      read 2,flow,a,w,h,viss,dens,dif
      read 3,amp,t,thk,rho,xmol,xin
      read 6,pb,wtp,ar,ybtm,pc,hlc
      read 7,abaro,eps,apt,pkden
      read 8,etaa,hkw,efic
      read 5,kount2
      if(kount2-2)15,19,15
   15 print 17
   17 format(17h input data error)
      go to 4
   19 do 199 i=1,5
      do 199 j=1,5
      flow1(i)=0.0
```

APPENDIX IV-7 (Cont'd)

MEDIATOR FUEL CELL COMPLETE DESIGN

```
131. =            amps(i,j)=0.0
132. =            volts(i,j)=0.0
133. =            grpow(i,j)=0.0
134. =            toth(i,j)=0.0
135. =            wracl(i,j)=0.0
136. =            wpecl(i,j)=0.0
137. =            xauw(i,j)=0.0
138. =            d(i,j)=0.0
139. =            xlbpkw(i,j)=0.0
140. =            xnpow(i,j)=0.0
141. =            alim(i)=0.0
142. =            celn(i,j)=0.0
143. =        199 continue
144. =      c     calculations per cell until statement 100
145. =            xtm=dens*1000.0-132.0*xmol
146. =            xmoll=xmt*(wtp/56.0+(1.0-wtp)/18.0)+xmol
147. =            btop=(1.0-xin)*xmol/xmoll
148. =            do 160 i=1,nvell
149. =            xi=i
150. =            flowl(i)=flow*xi
151. =            vell=flowl(i)/(a*w)
152. =            delc=0.347*(dif*dens/viss)**0.333*(viss*h/(dens*vell))**0.50
153. =      c     xmol = moles/lt, amps = ma/cm**2, x = moles ox. med/mols med.,
154. =      c     t = deg. cent.
155. =            alim(i)=dif*xmol*xin/(5.18e-6*(delc+1.182*(dif*h/vell)**0.50))
156. =            do 150 j=1,ncode
157. =            xj=j
158. =            amps(i,j)=amp*xj
159. =            delta=alim(i)-amps(i,j)
160. =            if(delta)150,150,21
161. =        210anum=1.0+5.18e-6*amps(i,j)/(dif*xmol*(1.0-xin))*(delc+1.182*(dif*h
                 4/vell)**0.50)
162. =            0dnum=1.0-5.18e-6*amps(i,j)/(dif*xmol*xin)*(delc+1.182*(dif*h/vell)
                 4**0.50)
163. =            etac=4.293e-5*(t+273.0)*alog(anum/dnum)
164. =            etao=0.2774-(0.0001*t+4.293e-5*(t+273.0)*alog(xin/(1.0-xin)))
165. =            etae=etac+etao
166. =            tvolt=1.249*(1.0-0.0008*t)
167. =            volts(i,j)=tvolt-(etaa+etae+0.001*rho*amps(i,j))
168. =            grpow(i,j)=amps(i,j)*volts(i,j)*h*w*0.001
169. =      c      column area calculation - 60 per cent flooding velocity
170. =            gprime=8.33e-8*(ar-0.50)*amps(i,j)*h*w
171. =            deng=0.39*pb/(273.0+t)
172. =            ratio=flowl(i)*dens/gprime*(deng/dens)**0.50
173. =            if(ratio-0.01)60,60,61
174. =         60 phi=0.25
175. =            go to 70
176. =         61 if(ratio-0.1)62,62,63
177. =         62 phi=0.055/ratio**0.356
178. =            go to 70
179. =         63 if(ratio-1.0)64,64,65
180. =         64 phi=0.021/ratio**0.74
181. =            go to 70
182. =      c     no data beyond ratio = 10 assume follows same curve
183. =         65 phi=0.020/ratio**1.15
184. =        700area=1.29e-2*(gprime**2.0*abaro*viss**0.20/(eps**3.0*dens*deng*phi
                 4))**0.50
185. =            gbtm=ar*amps(i,j)*0.001*h*w/(4.0*96500.0*area)
186. =            gtop=(ar-1.0)*amps(i,j)*0.001*h*w/(4.0*96500.0*area)
```

APPENDIX IV-7 (Cont'd)

MEDIATOR FUEL CELL COMPLETE DESIGN

```
187. =            xlm=flow1(i)*xmol1*0.001/area
188. =            bbtm=xmol/xmol1*(1.0+h*w*amps(i,j)/(2.0*96500.0*flow1(i)*xmol))
189. =      c     0.25 bearle sadles, abaro,abar ft**2/ft**3, apt-ft
190. =            ql=xlm*dens/xmol1
191. =            qg=(gbtm+gtop)*0.5*32.0
192. =            abar=abaro*(1.0-exp(-(47.3*ql/dens)))
193. =            hl=21.0*(viss*ql/(abar*dens**2.0))**0.333*(viss/(dens*dif))**0.667
194. =            hg=115.0/abaro*(qg*apt/viss)**0.34*(viss/(dens*dif))**0.667
195. =            hol=hl+xlm*pb/(gbtm*hlc*xmol1*0.001)*hg
196. =            btran=(gbtm*ybtm/(2.0*xlm)-bbtm)/(hg/hl-1.0)
197. =            delb=bbtm-btran
198. =            if(delb)29,29,30
199. =         29 btran=bbtm
200. =            go to 50
201. =         30 delt=btran-btop
202. =            if(delt)31,31,40
203. =         31 btran=btop
204. =         40 alfa=pb*ybtm-2.0*xlm*bbtm*pb/gbtm
205. =            beta=2.0*(xlm*pb/gbtm+xmol1*0.001*hlc)
206. =            aterm=hol/(xlm*pb/(gbtm*xmol1*0.001*hlc)+1.0)
207. =            ht1=aterm*alog((alfa-beta*bbtm)/(alfa-beta*btran))
208. =         50 ht2=hl*alog(btran/btop)
209. =            toth(i,j)=abs(ht1)+abs(ht2)
210. =      c     weight in lbs/cell
211. =           0wract=area*toth(i,j)*pkden/28320.0+xlm*dens*flow1(i)/(xmol1*toth(i
                 4,j)*0.001*454.0)
212. =        100 wpec=0.01467*h*w+a*w*h*dens/454.0+0.0483
213. =      c     from this point on calculations based upon overall system
214. =            celn(i,j)=1.15*hkw*1000.0/grpow(i,j)
215. =            d(i,j)=(area*celn(i,j)/0.785)**0.50
216. =            shwt=(d(i,j)*toth(i,j)*0.237+0.785*0.237*d(i,j)**2.0)*0.0023
217. =            wracl(i,j)=(wract*celn(i,j)+shwt)*1.10
218. =            wpecl(i,j)=wpec*celn(i,j)+1.935*h*w
219. =            xauw(i,j)=wracl(i,j)+wpecl(i,j)
220. =      c     parasitic power loss calculation
221. =            tarea=celn(i,j)*area
222. =            res=4.0*30.5*qg/(abaro*1.92e-4)
223. =            if(res-100.0)71,72,72
224. =         71 theta=13.1/res**0.538
225. =            go to 75
226. =         72 if(res-1000.0)73,74,74
227. =         73 theta=3.94/res**0.293
228. =            go to 75
229. =         74 theta=1.059/res**0.094
230. =         75 if(ql-0.27)76,77,77
231. =         76 al=1.20
232. =            go to 80
233. =         77 if(ql-1.08)78,79,79
234. =         78 al=2.14*ql**0.38
235. =            go to 80
236. =         79 al=1.78*ql**1.9
237. =        800scwl=3.28e-8*theta*abaro*(qg**2.0/(deng*eps**3.0))*toth(i,j)*tarea
                 4*al*(ql/dens+qg/deng)+0.101*(pb-pc)*celn(i,j)*flow1(i)
238. =            if(iopt-1)81,82,82
239. =         81 scwl=scwl+0.101*(gbtm-gtop)*tarea*(t+273.0)*82.06
240. =      c     pumping loss includes 1/2 inch connecting pipe
241. =         82 rec=2.0*flow1(i)*dens/(viss*(a+w))
242. =            if(rec-2100.0)83,83,84
243. =         83 f=16.0/rec
```

APPENDIX IV-7 (Cont'd)

MEDIATOR FUEL CELL COMPLETE DESIGN

```
244. =            go to 85
245. =         84 f=0.0014+0.125/rec**0.32
246. =         850cpl=flow1(i)*dens*(2.0*f*h*(a+w)/(a*w)+4.81+[tarea/1.28-1.0]**2] *
                 4(flow1(i)/(a*w))**2  *5.00e-8*celn(i,j)
247. =            pmpl=scwl+cpl
248. =            pumpl=pmpl/efic
249. =            xnepow=1150.*hkw-pumpl
250. =            xlbpkw(i,j)=xauw(i,j)/(xnepow*0.001)
251. =            xnpow(i,j)=xnepow*0.001
252. =        150 continue
253. =            print 171,t,tvolt,ncase,etao
254. =            if(ntral)87,87,86
255. =         86 ncode=1
256. =         87 if(noput-1)88,88,89
257. =         88 print 161,(flow1(i),volts(i,j),j=1,ncode)
258. =            print 162,(alim(i),amps(i,j),j=1,ncode)
259. =            print 163,(flow1(i),grpow(i,j),j=1,ncode)
260. =            print 164,(flow1(i),toth(i,j),j=1,ncode)
261. =            print 165,(flow1(i),wracl(i,j),j=1,ncode)
262. =            print 165,(flow1(i),wpecl(i,j),j=1,ncode)
263. =            print 166,(flow1(i),xauw(i,j),j=1,ncode)
264. =            print 167,(flow1(i),xnpow(i,j),j=1,ncode)
265. =            print 168,(flow1(i),xlbpkw(i,j),j=1,ncode)
266. =            print 169
267. =            go to 151
268. =         89 print 168,(flow1(i),xlbpkw(i,j),j=1,ncode)
269. =            print 165,(flow1(i),wracl(i,j),j=1,ncode)
270. =            print 165,(flow1(i),wpecl(i,j),j=1,ncode)
271. =        151 continue
272. =        171 format(2f8.4,i5,f8.4)
273. =        161 format(f6.1,15f6.3)
274. =        162 format(f7.2,15f6.1)
275. =        163 format(f6.1,15f7.2)
276. =        164 format(f6.1,15f7.2)
277. =        165 format(f6.1,15f7.2)
278. =        166 format(f6.1,15f7.2)
279. =        167 format(f6.1,15f7.3)
280. =        168 format(f6.1,15f7.2)
281. =        169 format(//)
282. =          1 format(6i5)
283. =          2 format(6f10.5,f10.7)
284. =          3 format(6f10.5)
285. =          6 format(5f10.5,e11.4)
286. =          7 format(4f10.5)
287. =          8 format(3f10.5)
288. =        160 continue
289. =            go to 4
290. =        190 stop
291. =            end
```

APPENDIX IV-8

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
292. +ready        command
101. -ready        compile[okren5]
292. +ready        start[0]
110. =i 05                                                                                                  1
117. =i 01       5     5     1     0     2     0
118. =i 02     10.0        0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03      25.0      40.0        0.050      0.15       1.00       0.90
120. =i 06      3.0       27.4        2.0        1.00       1.00     4.0    e<06
121. =i 07    274.0        0.68       0.0492    45.0
122. =i 08       0.00      1.00       0.85
123. =i 05                                                                                                  2
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     10.01795.89  10.001079.07  10.00 897.67  10.00    0.     10.00    0.
269. =o165     10.0  10.88  10.00    8.48  10.00    7.35  10.00    0.     10.00    0.
270. =o165     10.01396.86  10.001028.34  10.00 906.61  10.00    0.     10.00    0.
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     20.04651.47  20.001373.16  20.001027.49  20.00 894.65  20.00 829.17
269. =o165     20.0  15.06  20.00  10.99  20.00    9.53  20.00    8.67  20.00    8.19
270. =o165     20.01393.27  20.001025.16  20.00 902.33  20.00 841.43  20.00 807.60
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     30.02107.19  30.002389.68  30.001289.67  30.001027.53  30.00 910.11
269. =o165     30.0  20.39  30.00  13.03  30.00   11.08  30.00   10.04  30.00    9.36
270. =o165     30.01391.51  30.001023.73  30.00 900.88  30.00 839.56  30.00 803.16
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     40.0-509.44  40.006821.18  40.002211.61  40.001327.77  40.001070.07
269. =o165     40.0  27.55  40.00  15.19  40.00   12.45  40.00   11.17  40.00   10.37
270. =o165     40.01390.39  40.001022.84  40.00 900.04  40.00 838.64  40.00 801.95
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     50.0-204.12  50.00-849.51  50.000054.70  50.002518.18  50.001472.31
269. =o165     50.0  36.76  50.00  17.67  50.00   13.83  50.00   12.20  50.00   11.25
270. =o165     50.01389.59  50.001022.22  50.00 899.47  50.00 838.05  50.00 801.27
110. =i 05                                                                                                  1
117. =i 01       5     5     1     0     2     0
118. =i 02      25.0        0.20      22.86      14.60       0.014      1.23      .00001
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
119. =i 03     50.0      40.0       0.050      0.15       1.00       0.90
120. =i 06     3.0       27.4       2.0        1.00       1.00     4.0    e<06
121. =i 07   274.0        0.68      0.0492    45.0
122. =i 08     0.00       1.00      0.85
123. =i 05                                                                          2
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    25.01681.45  25.00 950.57  25.00    0.    25.00    0.    25.00    0.
269. =o165    25.0  12.02  25.00   9.40  25.00    0.    25.00    0.    25.00    0.
270. =o165    25.01024.34  25.00 840.28  25.00    0.    25.00    0.    25.00    0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    50.0-849.51  50.002518.18  50.001163.85  50.00 945.68  50.00    0.
269. =o165    50.0  17.67  50.00  12.20  50.00  10.61  50.00   9.95  50.00    0.
270. =o165    50.01022.22  50.00 838.05  50.00 776.92  50.00 748.79  50.00    0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    75.0-128.63  75.00-598.85  75.005259.60  75.002427.40  75.001513.73
269. =o165    75.0  25.78  75.00  14.83  75.00  12.37  75.00  11.25  75.00  10.95
270. =o165    75.01021.19  75.00 837.15  75.00 775.81  75.00 745.49  75.00 730.40
253. =o171   40.0000  1.2090    1  0.2439
268. =o168   100.0 -39.46 100.00-143.32 100.00-359.91 100.00-868.32 100.002775.46
269. =o165   100.0  37.04 100.00  17.91 100.00  14.11 100.00  12.55 100.00  11.72
270. =o165   100.01020.53 100.00 836.61 100.00 775.23 100.00 744.68 100.00 726.79
253. =o171   40.0000  1.2090    1  0.2439
268. =o168   125.0 -16.00 125.00 -55.05 125.00-122.49 125.00-229.39 125.00-397.08
269. =o165   125.0  51.66 125.00  21.64 125.00  16.00 125.00  13.84 125.00  12.73
270. =o165   125.01020.06 125.00 836.24 125.00 774.86 125.00 744.24 125.00 726.06
110. =i 05                                                                          1
110. =i 05
117. =i 01      5    5    1    0    2    0
118. =i 02    10.0       0.20     22.86     14.60      0.014     1.23     .00001
119. =i 03     25.0      40.0       0.050     0.15      1.00      0.90
120. =i 06      6.0      27.4       2.0       1.00      1.00    4.0    e<06
121. =i 07   274.0        0.68      0.0492   45.0
122. =i 08     0.00       1.00      0.85
123. =i 05                                                                          2
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    10.05329.86  10.001488.05  10.001089.87  10.00    0.    10.00    0.
269. =o165    10.0   8.20  10.00   6.30  10.00   5.59  10.00    0.    10.00    0.
270. =o165    10.01396.86  10.001028.34  10.00 906.61  10.00    0.    10.00    0.
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    20.02010.07  20.004386.34  20.001701.53  20.001246.41  20.001070.33
269. =o165    20.0  13.63  20.00   8.29  20.00   7.04  20.00   6.44  20.00   6.16
270. =o165    20.01393.27  20.001025.16  20.00 902.33  20.00 841.43  20.00 807.60
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    30.0-697.19  30.003354.94  30.004662.31  30.001952.41  30.001416.91
269. =o165    30.0  22.35  30.00  10.65  30.00   8.36  30.00   7.43  30.00   6.92
270. =o165    30.01391.51  30.001023.73  30.00 900.88  30.00 839.56  30.00 803.16
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    40.0-338.99  40.00-988.14  40.003974.02  40.006043.90  40.002325.23
269. =o165    40.0  34.68  40.00  13.75  40.00   9.86  40.00   8.42  40.00   7.68
270. =o165    40.01390.39  40.001022.84  40.00 900.04  40.00 838.64  40.00 801.95
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    50.0-181.50  50.00-483.49  50.001127.62  50.003542.02  50.001608.45
269. =o165    50.0  50.69  50.00  17.69  50.00  11.68  50.00   9.53  50.00   8.49
270. =o165    50.01389.59  50.001022.22  50.00 899.47  50.00 838.05  50.00 801.27
292. +ready       start[0]                                                          1
110. =i 05                                                                          1
117. =i 01      5    5    1    0    2    0
118. =i 02    10.0        0.20      22.86      14.60      0.014      1.23      .00001
119. =i 03     25.0      40.0        0.050      0.15      1.00       0.90
120. =i 06      9.0      27.4        2.0        1.00      1.00     4.0    e<06
121. =i 07   274.0        0.68       0.0492    45.0
122. =i 08      0.00      1.00       0.85
123. =i 05                                                                          2
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    10.05447.42  10.002406.57  10.001389.77  10.00   0.    10.00   0.
269. =o165    10.0   7.27  10.00   5.25  10.00   4.66  10.00   0.    10.00   0.
```

```
270. =o165    10.01396.86  10.001028.34  10.00 906.61  10.00   0.    10.00   0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    20.0-817.21  20.003584.52  20.005063.50  20.002069.66  20.001516.52
269. =o165    20.0  14.41  20.00   7.34  20.00   5.93  20.00   5.36  20.00   5.12
270. =o165    20.01393.27  20.001025.16  20.00 902.33  20.00 841.43  20.00 807.60
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    30.0-405.98  30.00-961.56  30.002769.95  30.004344.00  30.003278.24
269. =o165    30.0  26.33  30.00  10.36  30.00   7.40  30.00   6.32  30.00   5.79
270. =o165    30.01391.51  30.001023.73  30.00 900.88  30.00 839.56  30.00 803.16
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    40.0-239.93  40.00-511.60  40.001003.82  40.002230.04  40.000729.80
269. =o165    40.0  43.10  40.00  14.54  40.00   9.31  40.00   7.46  40.00   6.59
270. =o165    40.01390.39  40.001022.84  40.00 900.04  40.00 838.64  40.00 801.95
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    50.0-148.92  50.00-317.41  50.00-564.56  50.00-978.48  50.001822.24
269. =o165    50.0  64.65  50.00  19.93  50.00  11.71  50.00   8.85  50.00   7.52
270. =o165    50.01389.59  50.001022.22  50.00 899.47  50.00 838.05  50.00 801.27
110. =i 05
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
117. =i 01      5     5     1     0     2     0                                                  1
118. =i 02    10.0        0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03     25.0      40.0        0.050      0.15       1.00       0.90
120. =i 06     3.0       27.4        2.0        1.00       3.00     4.0    e<06
121. =i 07   274.0        0.68       0.0492    45.0
122. =i 08     0.00       1.00       0.85
123. =i 05                                                                                         2
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    10.01243.47  10.00 910.92  10.00 802.38  10.00    0.     10.00    0.
269. =o165    10.0  10.88  10.00   8.48  10.00   7.35  10.00    0.     10.00    0.
270. =o165    10.01396.86  10.001028.34  10.00 906.61  10.00    0.     10.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    20.01414.10  20.00 936.55  20.00 810.30  20.00 751.23  20.00 719.46
269. =o165    20.0  15.06  20.00  10.99  20.00   9.53  20.00   8.67  20.00   8.19
270. =o165    20.01393.27  20.001025.16  20.00 902.33  20.00 841.43  20.00 807.60
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    30.03844.75  30.001080.49  30.00 858.78  30.00 774.94  30.00 730.92
269. =o165    30.0  20.39  30.00  13.03  30.00  11.08  30.00  10.04  30.00   9.36
270. =o165    30.01391.51  30.001023.73  30.00 900.88  30.00 839.56  30.00 803.16
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    40.01011.08  40.001897.39  40.001032.12  40.00 851.81  40.00 774.59
269. =o165    40.0  27.55  40.00  15.19  40.00  12.45  40.00  11.17  40.00  10.37
270. =o165    40.01390.39  40.001022.84  40.00 900.04  40.00 838.64  40.00 801.95
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    50.0-271.00  50.002958.66  50.001836.82  50.001085.46  50.00 890.66
269. =o165    50.0  36.76  50.00  17.67  50.00  13.83  50.00  12.20  50.00  11.25
270. =o165    50.01389.59  50.001022.22  50.00 899.47  50.00 838.05  50.00 801.27
110. =i 05
117. =i 01      5     5     1     0     2     0                                                  1
118. =i 02    10.0        0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03     25.0      40.0        0.050      0.15       1.00       0.90
120. =i 06     6.0       27.4        2.0        1.00       1.00     4.0    e<06
121. =i 07   274.0        0.68       0.0492    45.0
122. =i 08     0.00       1.00       0.85
123. =i 05                                                                                         2
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    10.05329.86  10.001488.05  10.001089.87  10.00    0.     10.00    0.
269. =o165    10.0   8.20  10.00   6.30  10.00   5.59  10.00    0.     10.00    0.
270. =o165    10.01396.86  10.001028.34  10.00 906.61  10.00    0.     10.00    0.
237. =break  237.
292. +ready       start[0]
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
110. =i 05                                                                                                  1
117. =i 01      5     5     1     0     2     0
118. =i 02    10.0        0.20       22.86      14.60       0.014      1.23      .00001
119. =i 03     25.0      40.0         0.050      0.15       1.00       0.90
120. =i 06      6.0      27.4         2.0        1.00       6.00     4.0    e<06
121. =i 07   274.0        0.68        0.0492    45.0
122. =i 08      0.00      1.00        0.85
123. =i 05                                                                                                  2
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    10.01238.80  10.00 908.61  10.00 800.68  10.00    0.     10.00    0.
269. =o165    10.0   8.20  10.00   6.30  10.00   5.59  10.00    0.     10.00    0.
270. =o165    10.01396.86  10.001028.34  10.00 906.61  10.00    0.     10.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    20.01362.04  20.00 926.82  20.00 805.37  20.00 747.85  20.00 716.74
269. =o165    20.0  13.63  20.00   8.29  20.00   7.04  20.00   6.44  20.00   6.16
270. =o165    20.01393.27  20.001025.16  20.00 902.33  20.00 841.43  20.00 807.60
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    30.02501.40  30.001028.33  30.00 840.32  30.00 764.73  30.00 724.00
269. =o165    30.0  22.35  30.00  10.65  30.00   8.36  30.00   7.43  30.00   6.92
270. =o165    30.01391.51  30.001023.73  30.00 900.88  30.00 839.56  30.00 803.16
208. =break  208.
292. +ready       start[0]
110. =i 05                                                                                                  1
117. =i 01      5     5     1     0     2     0
118. =i 02    10.0        0.20       22.86      14.60       0.014      1.23      .00001
119. =i 03     25.0      40.0         0.050      0.15       1.00       0.90
120. =i 06      9.0      27.4         2.0        1.00       9.00     4.0    e<06
121. =i 07   274.0        0.68        0.0492    45.0
122. =i 08      0.00      1.00        0.85
123. =i 05                                                                                                  2
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    10.01236.91  10.00 907.50  10.00 799.79  10.00    0.     10.00    0.
269. =o165    10.0   7.27  10.00   5.25  10.00   4.66  10.00    0.     10.00    0.
270. =o165    10.01396.86  10.001028.34  10.00 906.61  10.00    0.     10.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    20.01340.61  20.00 922.65  20.00 803.15  20.00 746.25  20.00 715.40
269. =o165    20.0  14.41  20.00   7.34  20.00   5.93  20.00   5.36  20.00   5.12
270. =o165    20.01393.27  20.001025.16  20.00 902.33  20.00 841.43  20.00 807.60
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    30.02159.16  30.001006.63  30.00 832.31  30.00 760.18  30.00 720.83
269. =o165    30.0  26.33  30.00  10.36  30.00   7.40  30.00   6.32  30.00   5.79
269. =break  269.
292. +ready ;finish
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
quiktran at your service
quiktran assistance call 212 972-8991. hours 8am-10pm weekdays, 9am-4pm sat
ln28  ready ;user[bb5810,coat]
101. -ready        compile[okren5]
292. +ready        start[0]
110. =i 05                                                                                                  1
117. =i 01       5     5     1     0     2     0
118. =i 02     10.0        0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03      40.0      40.0        0.050      0.15       1.00       0.90
120. =i 06      3.0       27.4        2.0        1.00       1.00     4.0    e<06
121. =i 07    274.0        0.68       0.0492    45.0
122. =i 08      0.00       1.00       0.85
123. =i 05                                                                                                  2
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     10.01231.83  10.00 877.29  10.00    0.     10.00    0.     10.00    0.
269. =o165     10.0   9.18  10.00   7.20  10.00    0.     10.00    0.     10.00    0.
270. =o165     10.01120.47  10.00 891.98  10.00    0.     10.00    0.     10.00    0.
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     20.01739.55  20.00 992.16  20.00 838.11  20.00    0.     20.00    0.
269. =o165     20.0  11.97  20.00   9.33  20.00   8.23  20.00    0.     20.00    0.
270. =o165     20.01117.29  20.00 887.02  20.00 812.43  20.00    0.     20.00    0.
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     30.05689.86  30.001214.38  30.00 928.00  30.00    0.     30.00    0.
269. =o165     30.0  14.58  30.00  10.83  30.00   9.47  30.00    0.     30.00    0.
270. =o165     30.01115.78  30.00 885.53  30.00 809.17  30.00    0.     30.00    0.
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     40.01676.91  40.001896.70  40.001105.84  40.00 916.76  40.00    0.
269. =o165     40.0  17.61  40.00  12.13  40.00  10.50  40.00   9.64  40.00    0.
270. =o165     40.01114.84  40.00 884.69  40.00 808.05  40.00 770.57  40.00    0.
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     50.0-488.33  50.006275.75  50.001579.51  50.001094.53  50.00 945.68
269. =o165     50.0  21.29  50.00  13.41  50.00  11.41  50.00  10.41  50.00   9.95
270. =o165     50.01114.16  50.00 884.11  50.00 807.39  50.00 769.40  50.00 748.79
110. =i 05                                                                                                  1
117. =i 01       5     5     1     0     2     0
118. =i 02    100.00       0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03     100.0      40.0        0.050      0.15       1.00       0.90
120. =i 06      3.0       27.4        2.0        1.00       1.00     4.0    e<06
121. =i 07    274.0        0.68       0.0492    45.0
122. =i 08      0.00       1.00       0.85
123. =i 05                                                                                                  2
253. =o171    40.0000  1.2090     1  0.2439
268. =o168    100.0-143.32 100.00-868.32 100.00    0.    100.00    0.    100.00    0.
269. =o165    100.0  17.91 100.00  12.55 100.00    0.    100.00    0.    100.00    0.
270. =o165    100.0 836.61 100.00 744.68 100.00    0.    100.00    0.    100.00    0.
253. =o171    40.0000  1.2090     1  0.2439
268. =o168    200.0  -7.98 200.00 -28.75 200.00 -61.92 200.00 -99.35 200.00    0.
269. =o165    200.0  37.50 200.00  18.34 200.00  14.65 200.00  13.53 200.00    0.
270. =o165    200.0 835.53 200.00 743.53 200.00 713.05 200.00 699.17 200.00    0.
253. =o171    40.0000  1.2090     1  0.2439
268. =o168    300.0  -1.55 300.00  -5.41 300.00 -11.39 300.00 -18.94 300.00 -24.67
269. =o165    300.0  70.60 300.00  26.71 300.00  18.76 300.00  15.99 300.00  15.24
270. =o165    300.0 835.01 300.00 743.07 300.00 712.47 300.00 697.40 300.00 690.10
253. =o171    40.0000  1.2090     1  0.2439
268. =o168    400.0  -0.50 400.00  -1.68 400.00  -3.50 400.00  -5.84 400.00  -8.44
269. =o165    400.0 117.92 400.00  38.33 400.00  24.09 400.00  19.20 400.00  17.03
270. =o165    400.0 834.68 400.00 742.79 400.00 712.17 400.00 696.97 400.00 688.12
253. =o171    40.0000  1.2090     1  0.2439
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
268. =o168   500.0  -0.21 500.00  -0.68 500.00  -1.41 500.00  -2.35 500.00  -3.44
269. =o165   500.0 179.64 500.00  53.44 500.00  30.85 500.00  23.13 500.00  19.66
270. =o165   500.0 834.44 500.00 742.59 500.00 711.97 500.00 696.73 500.00 687.72
110. =i 05                                                                          1
117. =i 01     5    5    1    0    2    0
118. =i 02    10.0        0.20      22.86      14.60      0.014      1.23      .00001
119. =i 03    40.0       40.0        0.050      0.15      1.00       0.90
120. =i 06     3.0       27.4        2.0        1.00      3.00     4.0   e<06
121. =i 07   274.0        0.68       0.0492    45.0
122. =i 08     0.00       1.00       0.85
123. =i 05                                                                          2
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    10.0 993.42  10.00 789.38  10.00    0.     10.00    0.     10.00    0.
269. =o165    10.0   9.18  10.00   7.20  10.00    0.     10.00    0.     10.00    0.
270. =o165    10.01120.47  10.00 891.98  10.00    0.     10.00    0.     10.00    0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    20.01039.47  20.00 795.26  20.00 723.88  20.00    0.     20.00    0.
269. =o165    20.0  11.97  20.00   9.33  20.00   8.23  20.00    0.     20.00    0.
270. =o165    20.01117.29  20.00 887.02  20.00 812.43  20.00    0.     20.00    0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    30.01326.11  30.00 836.50  30.00 737.92  30.00    0.     30.00    0.
269. =o165    30.0  14.58  30.00  10.83  30.00   9.47  30.00    0.     30.00    0.
270. =o165    30.01115.78  30.00 885.53  30.00 809.17  30.00    0.     30.00    0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    40.05820.49  40.00 979.21  40.00 786.24  40.00 720.80  40.00    0.
269. =o165    40.0  17.61  40.00  12.13  40.00  10.50  40.00   9.64  40.00    0.
270. =o165    40.01114.84  40.00 884.69  40.00 808.05  40.00 770.57  40.00    0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    50.0-916.15  50.001554.98  50.00 916.94  50.00 780.62  50.00 728.82
269. =o165    50.0  21.29  50.00  13.41  50.00  11.41  50.00  10.41  50.00   9.95
270. =o165    50.01114.16  50.00 884.11  50.00 807.39  50.00 769.40  50.00 748.79
110. =i 05                                                                          1
117. =i 01     5    5    1    0    2    0
118. =i 02   100.00       0.20      22.86      14.60      0.014      1.23      .00001
119. =i 03    25.0       40.0        0.050      0.15      1.00       0.90
120. =i 06     3.0       27.4        2.0        1.00      1.00     4.0   e<06
121. =i 07   274.0        0.68       0.0492    45.0
122. =i 08     0.00       1.00       0.85
123. =i 05                                                                          2
253. =o171   40.0000  1.2090    1  0.2439
268. =o168   100.0 -13.05 100.00 -39.46 100.00 -81.62 100.00-143.32 100.00-231.70
269. =o165   100.0 115.77 100.00  37.04 100.00  22.90 100.00  17.91 100.00  15.50
270. =o165   100.01387.43 100.001020.53 100.00 897.98 100.00 836.61 100.00 799.78
253. =o171   40.0000  1.2090    1  0.2439
268. =o168   200.0  -0.91 200.00  -2.45 200.00  -4.80 200.00  -7.98 200.00 -11.96
269. =o165   200.0 443.02 200.00 116.56 200.00  57.67 200.00  37.50 200.00  28.29
270. =o165   200.01385.73 200.001019.18 200.00 896.80 200.00 835.53 200.00 798.74
253. =o171   40.0000  1.2090    1  0.2439
268. =o168   300.0  -0.22 300.00  -0.51 300.00  -0.96 300.00  -1.55 300.00  -2.30
269. =o165   300.0 990.85 300.00 252.89 300.00 117.27 300.00  70.60 300.00  49.34
270. =o165   300.01384.91 300.001018.51 300.00 896.22 300.00 835.01 300.00 798.25
253. =o171   40.0000  1.2090    1  0.2439
268. =o168   400.0  -0.09 400.00  -0.18 400.00  -0.32 400.00  -0.50 400.00  -0.73
269. =o165   400.01748.86 400.00 445.80 400.00 202.30 400.00 117.92 400.00  79.35
270. =o165   400.01384.40 400.001018.09 400.00 895.86 400.00 834.68 400.00 797.94
253. =o171   40.0000  1.2090    1  0.2439
268. =o168   500.0  -0.05 500.00  -0.08 500.00  -0.14 500.00  -0.21 500.00  -0.30
269. =o165   500.02706.87 500.00 694.19 500.00 312.73 500.00 179.64 500.00 118.56
270. =o165   500.01384.04 500.001017.79 500.00 895.59 500.00 834.44 500.00 797.72
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
110. =i 05                                                                                                  1
117. =i 01      5     5     1     0     2     0
118. =i 02    10.0        0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03     40.0      40.0        0.050      0.15       1.00       0.90
120. =i 06      9.0      27.4        2.0        1.00       9.00     4.0    e<06
121. =i 07   274.0        0.68       0.0492    45.0
122. =i 08      0.00      1.00       0.85
123. =i 05                                                                                                  2
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    10.0 989.34  10.00 786.90  10.00    0.     10.00    0.     10.00    0.
269. =o165    10.0   5.69  10.00   4.59  10.00    0.     10.00    0.     10.00    0.
270. =o165    10.01120.47  10.00 891.98  10.00    0.     10.00    0.     10.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    20.01017.51  20.00 788.71  20.00 719.72   20.00    0.     20.00    0.
269. =o165    20.0   8.68  20.00   5.78  20.00   5.13   20.00    0.     20.00    0.
270. =o165    20.01117.29  20.00 887.02  20.00 812.43   20.00    0.     20.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    30.01175.83  30.00 813.49  30.00 727.16   30.00    0.     30.00    0.
269. =o165    30.0  13.34  30.00   7.11  30.00   5.87   30.00    0.     30.00    0.
270. =o165    30.01115.78  30.00 885.53  30.00 809.17   30.00    0.     30.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    40.02067.82  40.00 893.49  40.00 755.66   40.00 703.42   40.00    0.
269. =o165    40.0  19.87  40.00   8.80  40.00   6.72   40.00   5.98   40.00    0.
270. =o165    40.01114.84  40.00 884.69  40.00 808.05   40.00 770.57   40.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    50.03277.78  50.001135.47  50.00 826.95   50.00 737.73   50.00 700.33
269. =o165    50.0  28.30  50.00  10.92  50.00   7.72   50.00   6.59   50.00   6.17
270. =o165    50.01114.16  50.00 884.11  50.00 807.39   50.00 769.40   50.00 748.79
110. =i 05
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
101. -ready        compile[okren5]
292. +ready        start[0]
110. =i 05                                                                                                  1
117. =i 01       5     5     1     0     2     0
118. =i 02     10.0        0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03      25.0      40.0        0.050      0.15       5.00       0.90
120. =i 06      3.0       27.4        2.0        1.00       3.00     4.0    e<06
121. =i 07    274.0        0.68       0.0492    45.0
122. =i 08      0.00       1.00       0.85
123. =i 05                                                                                                  2
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     10.01232.49  10.00 902.04  10.00 792.87  10.00 738.26  10.00 705.45
269. =o165     10.0  10.70  10.00   8.25  10.00   7.04  10.00   6.25  10.00   5.68
270. =o165     10.01385.26  10.001018.80  10.00 896.47  10.00 835.24  10.00 798.46
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     20.01397.03  20.00 927.90  20.00 803.08  20.00 743.97  20.00 709.27
269. =o165     20.0  14.87  20.00  10.76  20.00   9.27  20.00   8.34  20.00   7.67
270. =o165     20.01384.04  20.001017.79  20.00 895.59  20.00 834.44  20.00 797.72
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     30.03579.21  30.001063.29  30.00 848.84  30.00 766.89  30.00 723.16
269. =o165     30.0  20.17  30.00  12.80  30.00  10.82  30.00   9.74  30.00   9.00
270. =o165     30.01383.46  30.001017.30  30.00 895.16  30.00 834.05  30.00 797.36
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     40.01061.83  40.001796.25  40.001008.29  40.00 837.62  40.00 763.44
269. =o165     40.0  27.29  40.00  14.95  40.00  12.19  40.00  10.88  40.00  10.03
270. =o165     40.01383.11  40.001017.00  40.00 894.89  40.00 833.80  40.00 797.12
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     50.0-278.80  50.003597.92  50.001703.55  50.001046.77  50.00 867.71
269. =o165     50.0  36.43  50.00  17.41  50.00  13.56  50.00  11.91  50.00  10.93
270. =o165     50.01382.86  50.001016.78  50.00 894.69  50.00 833.62  50.00 796.96
110. =i 05                                                                                                  1
117. =i 01       5     5     1     0     2     0
118. =i 02     10.0        0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03      40.0      40.0        0.050      0.15       5.00       0.90
120. =i 06      3.0       27.4        2.0        1.00       3.00     4.0    e<06
121. =i 07    274.0        0.68       0.0492    45.0
122. =i 08      0.00       1.00       0.85
123. =i 05                                                                                                  2
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     10.0 984.09  10.00 779.22  10.00 710.92  10.00 676.69  10.00 656.13
269. =o165     10.0   8.97  10.00   6.86  10.00   5.78  10.00   5.11  10.00   4.63
270. =o165     10.01110.47  10.00 881.17  10.00 804.59  10.00 766.26  10.00 743.26
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     20.01029.32  20.00 788.13  20.00 715.02  20.00 679.28  20.00 658.02
269. =o165     20.0  11.77  20.00   9.05  20.00   7.79  20.00   6.97  20.00   6.38
270. =o165     20.01109.39  20.00 880.31  20.00 803.84  20.00 765.57  20.00 742.59
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     30.01298.37  30.00 827.13  30.00 730.21  30.00 687.53  30.00 663.35
269. =o165     30.0  14.36  30.00  10.56  30.00   9.13  30.00   8.23  30.00   7.59
270. =o165     30.01108.87  30.00 879.89  30.00 803.47  30.00 765.23  30.00 742.28
253. =o171    40.0000  1.2090     1  0.2439
268. =o168     40.04845.38  40.00 958.49  40.00 774.71  40.00 710.14  40.00 677.20
269. =o165     40.0  17.37  40.00  11.87  40.00  10.18  40.00   9.20  40.00   8.51
270. =o165     40.01108.54  40.00 879.62  40.00 803.24  40.00 765.02  40.00 742.08
253. =o171    40.0000  1.2090     1  0.2439
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
268. =o168    50.0-981.15  50.001463.07  50.00 892.13  50.00 763.92  50.00 708.55
269. =o165    50.0  21.02  50.00  13.14  50.00  11.10  50.00  10.01  50.00   9.28
270. =o165    50.01108.32  50.00 879.43  50.00 803.07  50.00 764.87  50.00 741.93
110. =i 05                                                                          1
117. =i 01      5    5    1    0    2    0
118. =i 02    10.0        0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03    100.0      40.0        0.050      0.15       5.00       0.90
120. =i 06     3.0       27.4        2.0        1.00       3.00    4.0   e<06
121. =i 07   274.0        0.68       0.0492    45.0
122. =i 08     0.00       1.00       0.85
123. =i 05                                                                          2
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    10.0 738.26  10.00 656.13  10.00 628.79  10.00 615.58  10.00   0.
269. =o165    10.0   6.25  10.00   4.63  10.00   3.88  10.00   3.47  10.00   0.
270. =o165    10.0 835.24  10.00 743.26  10.00 712.70  10.00 697.83  10.00   0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    20.0 743.97  20.00 658.02  20.00 629.86  20.00 615.92  20.00 607.75
269. =o165    20.0   8.34  20.00   6.38  20.00   5.42  20.00   4.83  20.00   4.44
270. =o165    20.0 834.44  20.00 742.59  20.00 711.97  20.00 696.73  20.00 687.72
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    30.0 766.89  30.00 663.35  30.00 632.47  30.00 617.57  30.00 608.85
269. =o165    30.0   9.74  30.00   7.59  30.00   6.51  30.00   5.84  30.00   5.38
270. =o165    30.0 834.05  30.00 742.28  30.00 711.67  30.00 696.40  30.00 687.30
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    40.0 837.62  40.00 677.20  40.00 638.58  40.00 621.18  40.00 611.31
269. =o165    40.0  10.88  40.00   8.51  40.00   7.37  40.00   6.64  40.00   6.14
270. =o165    40.0 833.80  40.00 742.08  40.00 711.48  40.00 696.21  40.00 687.09
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    50.01046.77  50.00 708.55  50.00 651.49  50.00 628.48  50.00 616.15
269. =o165    50.0  11.91  50.00   9.28  50.00   8.07  50.00   7.31  50.00   6.78
270. =o165    50.0 833.62  50.00 741.93  50.00 711.35  50.00 696.08  50.00 686.95
110. =i 05                                                                          1
117. =i 01      5    5    1    0    2    0
118. =i 02    10.0        0.20      22.86      14.60       0.014      1.23      .00001
119. =i 03   200.00      40.0        0.050      0.15       5.00       0.90
120. =i 06     3.0       27.4        2.0        1.00       3.00    4.0   e<06
121. =i 07   274.0        0.68       0.0492    45.0
122. =i 08     0.00       1.00       0.85
123. =i 05                                                                          2
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    10.0 656.13  10.00 615.58  10.00   0.    10.00   0.    10.00   0.
269. =o165    10.0   4.63  10.00   3.47  10.00   0.    10.00   0.    10.00   0.
270. =o165    10.0 743.26  10.00 697.83  10.00   0.    10.00   0.    10.00   0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    20.0 658.02  20.00 615.92  20.00 602.78  20.00   0.    20.00   0.
269. =o165    20.0   6.38  20.00   4.83  20.00   4.20  20.00   0.    20.00   0.
270. =o165    20.0 742.59  20.00 696.73  20.00 682.10  20.00   0.    20.00   0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    30.0 663.35  30.00 617.57  30.00 603.23  30.00   0.    30.00   0.
269. =o165    30.0   7.59  30.00   5.84  30.00   5.05  30.00   0.    30.00   0.
270. =o165    30.0 742.28  30.00 696.40  30.00 681.33  30.00   0.    30.00   0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    40.0 677.20  40.00 621.18  40.00 605.03  40.00 597.81  40.00   0.
269. =o165    40.0   8.51  40.00   6.64  40.00   5.77  40.00   5.30  40.00   0.
270. =o165    40.0 742.08  40.00 696.21  40.00 681.06  40.00 673.80  40.00   0.
253. =o171   40.0000  1.2090    1  0.2439
268. =o168    50.0 708.55  50.00 628.48  50.00 608.54  50.00 599.89  50.00 596.19
269. =o165    50.0   9.28  50.00   7.31  50.00   6.38  50.00   5.85  50.00   5.66
270. =o165    50.0 741.93  50.00 696.08  50.00 680.91  50.00 673.51  50.00 669.76
```

APPENDIX IV-8 (Cont'd)

MEDIATOR STACK DESIGN CALCULATIONS

(See Program for Format)

```
110. =i 05                                                                                                  1
117. =i 01      5     5     1     0     2     0
118. =i 02    10.0        0.20       22.86      14.60       0.014      1.23      .00001
119. =i 03    40.0       40.0        0.050       0.15      10.00       0.90
120. =i 06     3.0       27.4        2.0         1.00       3.00     4.0    e<06
121. =i 07   274.0        0.68       0.0492     45.0
122. =i 08     0.00       1.00       0.85
123. =i 05                                                                                                  2
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    10.0 994.66  10.00 785.43  10.00 715.51  10.00 680.40  10.00 659.25
269. =o165    10.0  22.99  10.00  15.54  10.00  12.43  10.00  10.65  10.00   9.46
270. =o165    10.01108.54  10.00 879.62  10.00 803.24  10.00 765.02  10.00 742.08
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    20.01048.36  20.00 799.37  20.00 723.36  20.00 686.06  20.00 663.81
269. =o165    20.0  34.55  20.00  23.17  20.00  18.47  20.00  15.78  20.00  14.00
270. =o165    20.01107.90  20.00 879.07  20.00 802.75  20.00 764.58  20.00 741.66
270. =break  270.
292. +ready       start[0]
110. =i 05                                                                                                  1
117. =i 01      5     5     1     0     2     0
118. =i 02    10.0        0.20       22.86      14.60       0.014      1.23      .00001
119. =i 03   200.00      40.0        0.050       0.15       5.00       0.90
120. =i 06     3.0       27.4        2.0         1.00       3.00     4.0    e<06
121. =i 07   274.0        0.68       0.0492     45.0
122. =i 08     0.00       1.00       0.85
123. =i 05                                                                                                  2
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    10.0 656.13  10.00 615.58  10.00    0.    10.00    0.    10.00    0.
269. =o165    10.0   4.63  10.00   3.47  10.00    0.    10.00    0.    10.00    0.
270. =o165    10.0 743.26  10.00 697.83  10.00    0.    10.00    0.    10.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    20.0 658.02  20.00 615.92  20.00 602.78  20.00    0.    20.00    0.
269. =o165    20.0   6.38  20.00   4.83  20.00   4.20  20.00    0.    20.00    0.
270. =o165    20.0 742.59  20.00 696.73  20.00 682.10  20.00    0.    20.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    30.0 663.35  30.00 617.57  30.00 603.23  30.00    0.    30.00    0.
269. =o165    30.0   7.59  30.00   5.84  30.00   5.05  30.00    0.    30.00    0.
270. =o165    30.0 742.28  30.00 696.40  30.00 681.33  30.00    0.    30.00    0.
253. =o171   40.0000  1.2090     1  0.2439 .
268. =o168    40.0 677.20  40.00 621.18  40.00 605.03  40.00 597.81  40.00    0.
269. =o165    40.0   8.51  40.00   6.64  40.00   5.77  40.00   5.30  40.00    0.
270. =o165    40.0 742.08  40.00 696.21  40.00 681.06  40.00 673.80  40.00    0.
253. =o171   40.0000  1.2090     1  0.2439
268. =o168    50.0 708.55  50.00 628.48  50.00 608.54  50.00 599.89  50.00 596.19
269. =o165    50.0   9.28  50.00   7.31  50.00   6.38  50.00   5.85  50.00   5.66
270. =o165    50.0 741.93  50.00 696.08  50.00 680.91  50.00 673.51  50.00 669.76
110. =i 05
```