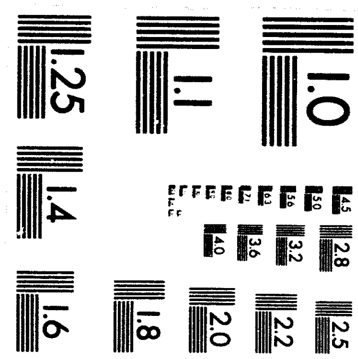
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# Fuel Cell Handbook Update

Authors:
W.R. Owens
J.H. Hirschenhofer
R.R. Engleman Jr.
D.B. Stauffer



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Gilbert/Commonwealth, Inc.
P.O. Box 1498
Reading, PA 19603

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Morgantown, West Virginia

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# DISCLAIMER

# P18 Fuel Cell Handbook Update

## CONTRACT INFORMATION

| | |
|---|---|
| Contract Number | DE - AC01 - 88FE61684 |
| Contractor | Gilbert/Commonwealth, Inc.<br>P.O. Box 1498<br>Reading, PA 19603<br>(215)775-2600 |
| Contractor Project Manager | William R. Owens |
| Principal Investigators | John H. Hirschenhofer<br>Ronald R. Engleman Jr.<br>David B. Stauffer |
| METC Project Manager | Diane T. Hooie |
| Period of Performance | June 15, 1992 to June 25, 1993 |

## OBJECTIVES

The objective of this work was to update the 1988 version of DOE's Fuel Cell Handbook. Significant developments in the various fuel cell technologies required revisions to reflect state-of-the-art configurations and performance. The theoretical presentation was refined in order to make the handbook more useful to both the casual reader and fuel cell or systems analyst. In order to further emphasize the practical application of fuel cell technologies, the system integration information was expanded. In addition, practical elements, such as suggestions and guidelines to approximate fuel cell performance, were provided.

## BACKGROUND INFORMATION

In 1980 the Institute of Gas Technology (IGT) published the "Handbook of Fuel Cell Performance" under a DOE contract. This document was later revised in 1988 under another DOE contract by Lawrence Berkeley Laboratory to become "Fuel Cells, A Handbook". These previous publications serve as the basis for this latest version.

The current version has the same format and organization of the 1988 handbook. Specific information from the 1988 handbook was also retained where applicable. It was determined, however, that the scope of the handbook should be adjusted for an expanded audience. The increased interest in fuel cells by those not directly familiar with the technology or those interested in potentially using the technology requires a more practical and applications oriented approach.

Some of the more detailed electrochemical information that appeared in the 1988 handbook was removed. The theoretical background that was emphasized in the 1988 handbook was replaced by information concerning performance predictions of fuel cell technologies. The use of experimentally based equations to clearly define important operating parameters was drawn from the 1980 version of the handbook. Recent experimentally derived data was used to update the coefficients of these equations. Data was gathered from a variety of sources which included fuel cell contractors and published information from both domestic and international sources.

In order to provide additional information on technology application for potential users desiring to assess the technology, the presentation on fuel cell systems was expanded. Issues related to system integration were described. A series of typical power plant designs were included to illustrate operating characteristics.

## PROJECT DESCRIPTION

The research and analysis involved in this update included personal interviews of researchers involved in fuel cell material, component and system testing. Additional information was gathered through an extensive literature search of fuel cell papers published since 1988. These papers outlined domestic research in fuel cells as well as both European and Japanese efforts.

Each fuel cell type was essentially treated as a separate technology. The most promising developments in materials and design configurations for each fuel cell type were described in order to give an overview of current technology development. This overview also gives the likely course of future research as these technologies continue to approach commercialization. The inherent strengths and weaknesses of each technology were emphasized throughout to assist in determining possible application scenarios.

Recent experimental data was used to update or develop equations describing the performance of the various fuel cell types. The equations are theoretically based and define the change in cell voltage as a result of an increase or a decrease in a specific parameter. The following operational variables are the key parameters used in these equations: pressure, temperature, oxidant and fuel utilizations, contaminant level, current density and operational life.

The effect of each parameter essentially needed to be determined independently of the others. Data showing the effect on performance by changing only one parameter at a time was used. Data from different sources was analyzed in order to provide a more balanced depiction of typical cell performance. Comparing data from different sources, however, was often difficult due to variations in base operating conditions. This data needed to be normalized as best as possible in order to provide for a more direct comparison. Linear regression was used to determine standard performance curves. Data from these performance curves was then used to calculate the constant coefficients of the equations. The coefficients for these equations is what reflects the current state-of-the-art performance of the particular fuel cell type.

The system integration material that was added outlined typical conceptual designs of fuel cell power plants. This material was based on ASPEN/SP simulation code. Performance and flow characteristics were described and a system schematics were included.

## RESULTS

The primary result of working on the handbook was the updating of equations which describe the performance of the different fuel cell technologies. A summary of these equations, as well as the variable ranges for which they are applicable, appears in Tables 1, 2 and 3. The best estimate of the coefficients for these equations is included. The text of the handbook presents other possible coefficients for these equations when the data was difficult to normalize and a direct comparison could not be made between different sources. These coefficients, along with operating information, were presented as possible alternatives to the ones found in the tables.

The three most advanced fuel cell technologies, PAFC, MCFC and SOFC, appear in the tables. Experimental data for polymer electrolyte fuel cells (PEFC's) was also reviewed. It was determined, however, that more extensive test data is required before typical performance equations could be defined. Recent data for PEFC's describing the effect on performance from changes in operating variables was summarized in the text of the handbook.

**Table 1. Summary of PAFC Performance Equations**

| Parameter | Equation | Comments |
|---|---|---|
| Pressure | $\Delta V_P(mV) = 146 \log (P_2/P_1)$ | $1\ atm \leq P \leq 10\ atm$<br>$177^oC \leq T \leq 218^oC$ |
| Temperature | $\Delta V_T(mV) = 1.15\ (T_2 - T_1)$ | $180^oC \leq T \leq 250^oC$ |
| Oxidant | $\Delta V_c(mV) = 148 \log (P_{O2})_2/(P_{O2})_1$<br>$\Delta V_c(mV) = 96 \log (P_{O2})_2/(P_{O2})_1$ | $0.04 \leq P_{O2}/P_{Total} \leq 0.20$<br>$0.20 < P_{O2}/P_{Total} < 1.0$ |
| Fuel | $\Delta V_a(mV) = 55 \log (P_{H2})_2/(P_{H2})_1$ | $0.55 \leq P_{H2}/P_{Total} \leq 0.65$ |
| CO Poisoning | $\Delta V_{CO}(mV) = -11.1\ ([CO]_2 - [CO]_1)$<br>$\Delta V_{CO}(mV) = -6.14\ ([CO]_2 - [CO]_1)$<br>$\Delta V_{CO}(mV) = -3.54\ ([CO]_2 - [CO]_1)$<br>$\Delta V_{CO}(mV) = -2.05\ ([CO]_2 - [CO]_1)$<br>$\Delta V_{CO}(mV) = -1.30\ ([CO]_2 - [CO]_1)$ | $163^oC$<br>$177^oC$<br>$190^oC$<br>$204^oC$<br>$218^o$ |
| Current Density | $\Delta V_J(mV) = -0.53\ \Delta J$<br><br>$\Delta V_J(mV) = -0.39\ \Delta J$<br><br>$\Delta V_J(mV) = -0.74\ \Delta J$<br><br>$\Delta V_J(mV) = -0.45\ \Delta J$ | $100mA/cm^2 \leq J \leq 200mA/cm^2$<br>8.2 atm<br>$200mA/cm^2 < J \leq 650mA/cm^2$<br>8.2 atm<br>$50mA/cm^2 \leq J \leq 120mA/cm^2$<br>1 atm<br>$120mA/cm^2 < J \leq 215mA/cm^2$<br>1 atm |
| Life Effects | $\Delta V_{lifetime}(mV) = -4\ mV/1000\ hours$ | |

**Table 2. Summary of MCFC Performance Equations**

| Parameter | Equation | Comments |
|---|---|---|
| Pressure | $\Delta V_P(mV) = 76.5 \log (P_2/P_1)$ | $1\ atm \leq P \leq 10\ atm$ |
| Temperature | $\Delta V_T(mV) = 2.16\ (T_2 - T_1)$<br>$\Delta V_T(mV) = 1.40\ (T_2 - T_1)$<br>$\Delta V_T(mV) = -0.25\ (T_2 - T_1)$ | $575^oC \leq T < 600^oC$<br>$600^oC \leq T \leq 650^oC$<br>$650^oC < T \leq 700^oC$ |
| Oxidant | $\Delta V_c(mV) = 250 \log (P_{CO2}P_{O2}^{1/2})_2/(P_{CO2}P_{O2}^{1/2})_1$<br>$\Delta V_c(mV) = 99 \log (P_{CO2}P_{O2}^{1/2})_2/(P_{CO2}P_{O2}^{1/2})_1$ | $0.04 \leq P_{CO2}/P_{O2}^{1/2} \leq 0.11$<br>$0.11 < P_{O2}/P_{O2}^{1/2} \leq 0.38$ |
| Fuel | $\Delta V_a(mV) = 173 \log (P_{H2}/P_{CO2}P_{H2O}^{1/2})_2/(P_{H2}/P_{CO2}P_{H2O}^{1/2})_1$ | $3.8 \leq P_{H2}/P_{CO2}P_{H2O}^{1/2} \leq 17.5$ |
| Current Density | $\Delta V_J(mV) = -1.21\ \Delta J$<br>$\Delta V_J(mV) = -1.76\ \Delta J$ | $50mA/cm^2 \leq J \leq 150mA/cm^2$<br>$150mA/cm^2 < J \leq 200mA/cm^2$ |
| Life Effects | $\Delta V_{lifetime}(mV) = -5\ mV/1000\ hours$ | |

**Table 3. Summary of SOFC Performance Equations**

| Parameter | Equation | Comments |
|---|---|---|
| Pressure | $\Delta V_P(mV) = 59 \log (P_2/P_1)$ | $1\ atm \leq P \leq 10\ atm$ |
| Temperature | $\Delta V_T(mV) = 1.31\ (T_2 - T_1)$<br>$\Delta V_T(mV) = 0.41\ (T_2 - T_1)$ | $800^oC \leq T < 900^oC$<br>$900^oC \leq T \leq 1000^oC$ |
| Oxidant | $\Delta V_c(mV) = 92 \log (P_{O2})_2/(P_{O2})_1$ | $0.16 \leq P_{O2}/P_{Total} \leq 0.20$ |
| Fuel | $\Delta V_a(mV) = 159 \log (P_{H2}/P_{H2O})_2/(P_{H2}/P_{H2O})_1$ | $1.39 \leq P_{H2}/P_{H2O} \leq 6.87$ |
| Current Density | $\Delta V_J(mV) = -0.73\ \Delta J$ | $50mA/cm^2 \leq J \leq 400mA/cm^2$<br>1 atm |
| Life Effects | $\Delta V_{lifetime}(mV) = -10\ mV/1000\ hours$ | |

## FUTURE WORK

The current version of the fuel cell handbook is in draft form and is being reviewed by DOE and others independent parties. This draft will be revised according to the suggestions and comments obtained through this review process. Upon approval from DOE a final version will be submitted as both a hard and electronic copy. This electronic copy will assist in the efficient update of this handbook in the future.

## REFERENCES

*Fuel Cells, A Handbook* (DRAFT), Contract No. DE-AC01-88FE61684, 1993.

*Fuel Cells, A Handbook*, DOE/METC-88/6096, NTIS-DE88010252

*Handbook of Fuel Cell Performance*, Contract No. EC-77-C-03-1545, 1980.

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