IECEC-98-1271
33rd Intersociety Engineering Conference on Energy Conversion
Colorado Springs, CO, August 2-6, 1998

CRITICAL FACTORS IN TRANSITIONING FROM FUEL CELL TO COLD FUSION TECHNOLOGY

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ABSTRACT

The fuel cell industry possesses much of the required manufacturing equipment and knowledge-base (e.g., proton conduction and hydrogen safety) necessary to develop cold fusion systems. Key factors in making a transition to cold fusion technology are discussed. Loading of reaction material can be provided by electrolytic charging and high gas over-pressure. Effective pressures over 10,000 atmospheres are required in cold fusion systems, giving a loading of H/M = 1; and a combination of loading methods is highly desirable. Systems must be designed to provide continuous flow of hydrogen ions ($\approx 10^{17}$/sec for ten kilowatts), with an input power source of 50 watts (est.). Cold fusion experiments have shown that helium is formed during the reaction, and physical changes occur in the reaction material. These revelations impact design and operation of cold fusion systems, as the reaction material must be replaced periodically, while the systems must maintain integrity during operation. Safety and cost are also highly important considerations.

I. INTRODUCTION

Hydrogen in metals is a historically well-studied subject because of interest in embrittlement of metals and their failure mechanisms. Recent interest has been related to development of new devices such as improved proton conduction fuel cells and hydrogen generators. R&D organizations working on fuel cells in particular already possess much of the knowledge-base and manufacturing know-how necessary to transition into cold fusion technology.

The benefit of cold fusion derives from the interaction between chemical and nuclear forces within a reaction material; energy appears to be released by nuclear fission, nuclear fusion, a combination of fusion and fission or fusion and fission operating seperately. Many scientists, engineers and investors have given cold fusion serious attention since Pons and Fleischmann discovered it in the mid-to-late 1980s.[1] The New Energy Partners venture capital firm, for example, has supported companies with working prototypes, and several prototypes are being tested to determine heat output levels and reaction rates.[2] Approximately 1500 papers from technical journals and conferences have reported some degree of replication of the cold fusion effect (800 in U.S.); 300 related patent applications have been developed in the U.S.; and, 100 patents have been granted in Japan.[3]

II. PROTON CONDUCTION AND LOADING

Achievement of high concentrations of hydrogen isotopes (i.e., deuterium, protium, or both) within metal reaction material (Figure 1), is considered to be paramount in rendering operable cold fusion systems.[4] Concentrations close to 1 (H/M ≈ 1) have been shown to be possible for powdered palladium metal when the externally applied pressure is 10-15 kbar (25°C). This level of loading is difficult to attain, first, because the number of metal atoms (M) is a large quantity. Other metals, such as nickel, require higher pressures to achieve this degree of loading. Still higher pressures are required at higher temperatures.

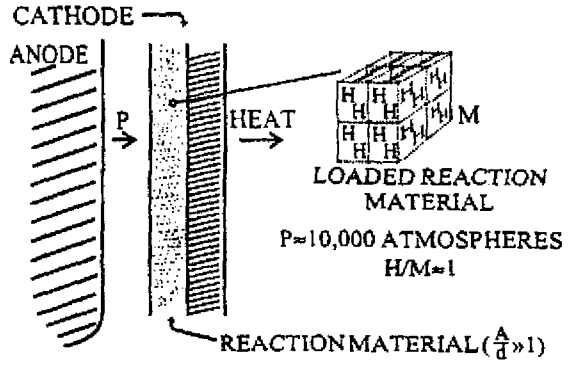

FIGURE 1. TYPICAL ELECTRODE CONFIGURATION

In order to design operable systems, it is absolutely necessary to invest effort in understanding the work by M. Enyo at Hokkaido University regarding the several types of disassociation mechanisms responsible for producing hydrogen atoms as intermediate species. Loading is described in terms of chemical potentials discussed in physical chemistry and thermodynamics. Enyo in the mid-1970s made an assumption that rates for all reaction steps may be of the same magnitude, rather than imposing a constraint that there is a single rate-determining step. From this, he derived equations describing variation of activity of the intermediate hydrogen species with electric overpotential, η ($\eta = -\Delta\mu/F$, where μ is chemical potential and F is Faraday's constant). Enyo showed that the amount of loading varies with overpotential. Indeed, the equivalence between hydrogen gas pressure and electrical overpotential means that a change in activity of the intermediate species produced by the overpotential is equal in magnitude to that produced when pressure is increased from its equilibrium value.[5]

Enyo went even further to show that, due to competing disassociation mechanisms, greater overpotential would be required to produce a given loading than that calculated by the generally-used Nernst equation. His data from the early 1980s may be used as a guide in determining best overpotential levels to use. He demonstrated reasons for previously measured values of H/M = 0.7 in the bulk of palladium at 1 atm, and for the increase in loading obtained as pressure or overpotential is increased. After the quantity of hydrogen to metal (H/M) is up in the vicinity around 0.9-1, very large increases in external pressure are required for small increases in concentration.[6-7]

Two other effects make the required level of loading difficult to attain. Electrical resistance of loaded metals varies as hydrogen concentration increases. Compensation must be provided for the variation in electrical resistance by means of a suitably-sized power supply. Secondly, hydrogen concentration, and consequently, reaction rate will not be uniform across the volume of reaction material *even* when steady state conditions are reached, but will be localized into a thin region. The localized concentration of hydrogen will move about in response to changes from the steady state. This is demonstrated in equations of hydrogen flux through the reaction material by the sum of a drift term due to electric field and a diffusive term caused by temperature gradient. The localization and movement of hydrogen in the reaction material have important consequences. As a result, a long electrode with a large surface area is much better than a thick one. And, there will always be continuous leakage of hydrogen out of the system. The amount of loading achieved will depend to a large extent on how well leakage can be prevented. The physics behind these considerations is discussed in Hydrogen in Metals II, Application Oriented Properties, published in 1978.[8]

Due to these difficulties in obtaining high loading, cold fusion systems should be designed to be loaded via a combination of physical pressure and electric field. Moderate gas pressure may be obtained by bottled gases. Notable efforts have been conducted at the Los Alamos National Laboratory in high pressure charging.[9] If the objective is to produce 500 watts to 50 kilowatts continuously, the flow rate should be about 10^{17} per second. A simple proton conduction model that takes into account the work required to transfer this number of charges into the reaction material, plus additional current required as the reaction material changes, indicates that the input power source should be capable of providing 50 watts. Specifically, 10 watts are required to move the positive charge into the reaction material, and several times this is required against a phantom current produced as the reaction proceeds. A 2-to-1 design margin could be provided by a 100 watt d.c. power supply. A sense of the high efficiency of cold fusion systems can be obtained from this information. In comparison, future hydrogen fuel cells are projected to have an efficiency of 0.70 for converting heat to electricity (ε = 0.70) , e.g., 10 kilowatts of electricity from 14 kilowatts (heat) input.

III. MAINTENANCE

Reaction material will become deactivated during operation by microscopic high temperature fracture, melting and material segregation, by hydride formation, and by buildup of reaction products. Experimental data show that helium is produced as a result of cold fusion reactions. Other chemical elements that originally were

not detected in the starting reaction material also appear to form. Methods must, therefore, be developed to collect helium gas produced during operation of cold fusion systems and to replace spent reaction material periodically. As the systems must maintain integrity during operation, development of these methods is a key challenge area.

Collection volumes and replacement intervals can be roughly determined from quantities of helium and other elements measured in cold fusion research. The most notable efforts to quantify helium were conducted by M. Miles and associates at the Naval Air Warfare Center, China Lake and by Y. Arata at Osaka University.[10-11] Additionally, mechanisms have been determined for forming helium bubbles in metal reaction material and their subsequent release.[12] China Lake's data indicate that helium is produced at a rate of 10^{11}-10^{12} atoms per second per watt, and is commensurate with heat measured. Arata's data confirm that helium is produced. Due to the small quantities of helium, collection bottles in operating systems can be small and easily handled.

Chemical elements in spent electrodes were measured by a number of methods, such as energy dispersive x-ray analysis and secondary ion mass spectroscopy. While strong residual radiation typical of nuclear power plant fuel is not present, some mild type of radiation has been observed.[13] Relative quantities of elements in the electrodes can begin to be estimated from results obtained by T. Mizuno at Hokkaido University for palladium and G. Miley at Urbana for nickel.[14-15] The uranium-235 fission yield curve (a) of Figure 2 was plotted to illustrate some of their results. Parts of Mizuno's data (b) indicate that 0.12% Cr-52, 0.6% Cr-53, 0.009% Mn-54, 0.06% Fe-56, 0.02% Fe-57, 0.12% Cu-63, 0.11% Zn-64, 0.08% Zn-66, 0.06% Zn-68 and 0.0005% Ga-69 were measured relative to 100% palladium. The largest value (Cu-63) was assumed to be comparable to the value for the peak of the uranium fission yield curve and the value for Mn-54 was assumed to represent a minimum at the midpoint of data, as this isotope has a mass that is half of the mass of Pd-108. Parts of Miley's data (c) are plotted by assuming that they surround a midpoint at A=29-30, half of the mass of Ni-58, 59. Insufficient data and resolution in the measurements prevent definitive conclusions to be drawn concerning reaction processes. It is interesting to note that hypothetical palladium and nickel "fission yield curves" appear to have the same width-to-midpoint ratio as the uranium fission yield curve. Mizuno and Miley reported data for many new species that are not shown here, many of which have masses close to palladium and nickel reaction material. Benefits of reprocessing the reaction material may be estimated from these types of data.

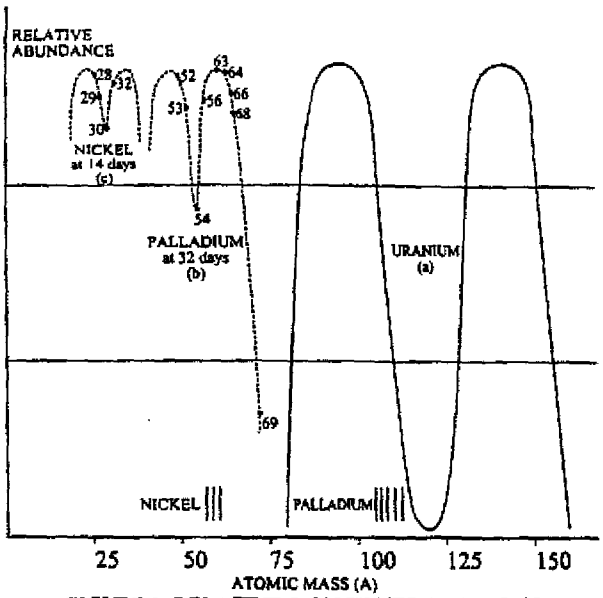

FIGURE 2. RELATIVE QUANTITIES OF SPECIES FORMED IN ELECTRODES

IV. SAFETY

Safety is of primary concern in cold fusion technology, due to the potential for hydrogen and hydrocarbon reactions and high pressure explosions.[16] Stringent precautions must be applied in system and experimental design. Safety barriers between the cold fusion reactor and experimenter are depicted in Figure 3.[17] Operational designs should ensure that systems will be kept sealed as much as possible to preventing entry of oxygen and hydrocarbons. In this experimental arrangement, the many tubes and valves have the purpose of keeping the system sealed after reaction material is installed and the reactor connected. The chance for unloading of hydrogen in the reaction material is reduced by maintaining voltage across the system with an uninterruptible power supply. Experimenters should comply with American National Standards Institute (ANSI) standards for hydrogen and oxygen containing components. Components must be able to contain, or otherwise respond to, abnormally high internal pressures that may develop during operation. Particular care should be given to joints, welds and strength variations between components. Protective jackets can be utilized in operational systems to ensure that malfunctions do not damage outside areas; in the experimental layout, this is provided by a separate enclosure for the reactor. Protective jackets should be designed to prevent maintenance by untrained persons. Pressure sensors and pressure relief

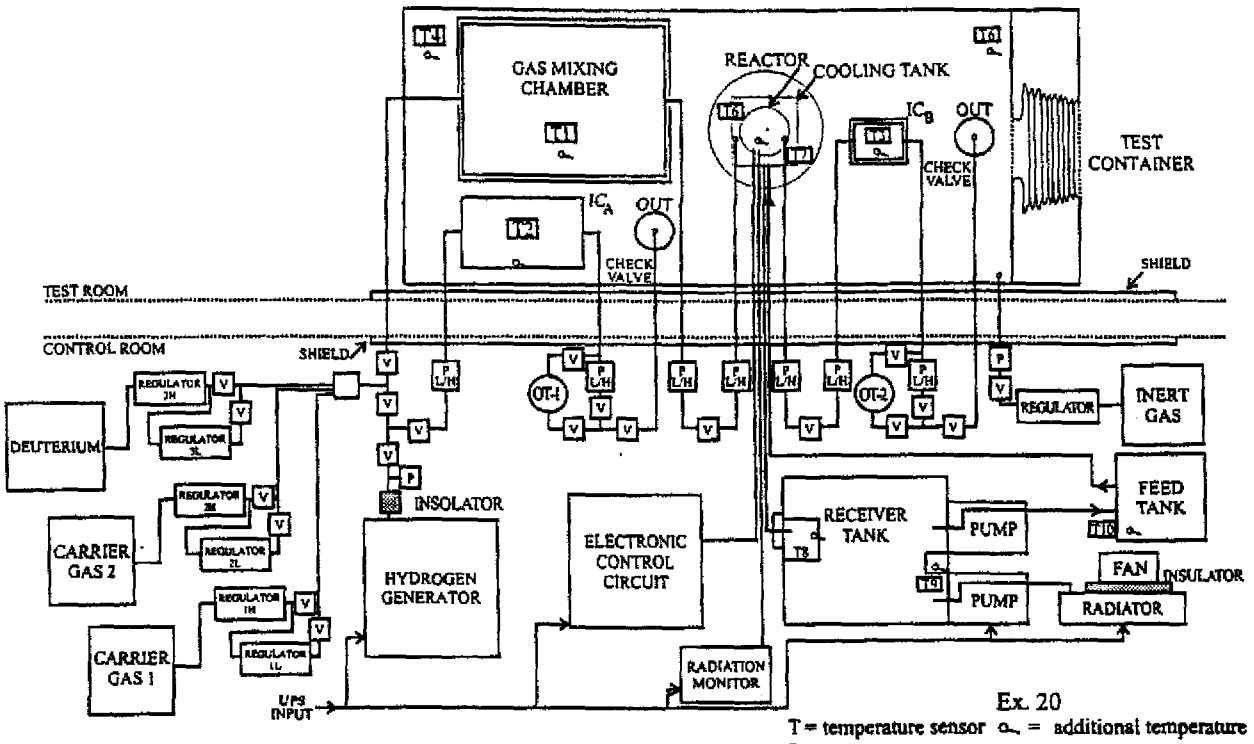

FIGURE 3. EXPERIMENTAL DESIGN WITH SAFETY CONSIDERATION

devices can be used to detect and respond to unusually high pressure conditions. The possibility of very rapid unloading also implies the need for stringent safety precautions when handling spent reaction material. Designs should ensure that spent material can be safely removed by a maintenance technician, transported to a reprocessing center, re-manufactured into new reaction material, and that the new reaction material could be safely installed.

V. COST FACTORS

Cold fusion technology may permit energy independence for the individual homeowner and nation-states; and, development of kilowatt systems could be an important advancement in national and international security. Life cycle costs for individual, homeowner-type 10kW units can be estimated and compared to the cost of electricity produced by oil and nuclear power plants. Estimates of natural resources used may also be developed. As indicated in Figure 4, provisioning and maintenance over long use periods should be included in cost estimates.

The authors estimate that the system will cost $30k over 30 years, including reactor, electronic controller, installation and replacement parts. Gas service should cost $7-8k and a service contract about $10k. Replacement reaction material is estimated to be $20-30k. The total of these amounts results in less than 3¢/kWH for the cost of electricity, which compares very favorably with the least cost of electricity from the power grid. Additionally, waste heat from the unit would be provided at no cost. Exemption from any future global pollution tax would certainly be expected, as cold fusion systems should contribute significantly to conserving national and international resources. Only a small fraction of the 10^{40} hydrogen isotope atoms available from sea water would be used, even if all 800 million earth households were provided 10kW units. Spent gases and reaction material could be collected locally and reprocessed by new commercial enterprises to provide additional benefits.

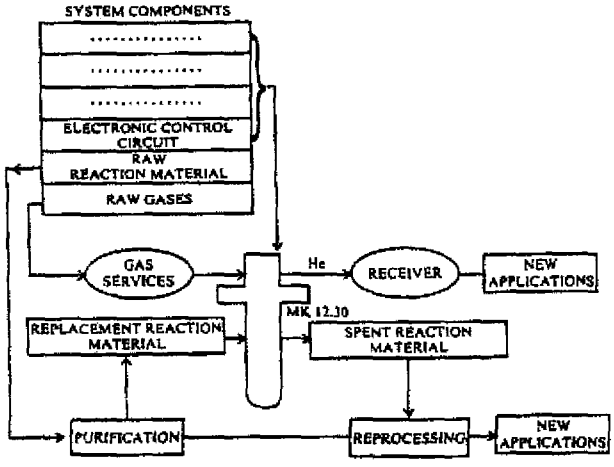

FIGURE 4. COMPONENT/PRODUCT FLOW/COST ESTIMATION DIAGRAM

NOMENCLATURE

F Faraday's constant

H atoms of deuterium, protium, or both

M atoms of reaction material

η electric overpotential

μ chemical potential

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