Recent advances in SPE® water electrolyzer

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Abstract

A new cell structure has been introduced into the SPE water electrolyzer which has improved overall characteristics significantly. Weight, reliability, and efficiency are the characteristics that are improved the most, with volume having a second order improvement. This paper discusses the capabilities of the new cell structure and the impact it would have in various space applications.

Introduction

In recent years, high pressure water electrolysis has been considered for several space applications. These space applications include the generation of high pressure hydrogen and oxygen for space station reboost propulsion, the generation of high pressure hydrogen and oxygen for lunar base energy storage, and the generation of high pressure oxygen for on-orbit space suit oxygen supply recharge. The technical approach taken with the SPE* water electrolyzer has been to use the previously developed nuclear submarine SPE electrolyzer design while reducing mass wherever possible. Because the basic nuclear submarine SPE electrolyzer cell design is limited to approximately 400 psi differential pressures overboard and across the cell, the stack of cells must be pressure balanced in a nitrogen-filled dome when operating above 400 psi. This results in significant mass and system complexity.

Within the last two years, a new SPE water electrolyzer cell structure has been developed. This cell structure, which has a lower mass than the 400 psi design, requires no pressure-balanced dome when operating at elevated pressures (i.e., up to several thousand psi). This cell structure is configured to permit the hydrogen and oxygen compartments to operate at different pressures equivalent to the maximum system pressure and, finally, this cell structure results in lower cell voltage (i.e., higher efficiency).

Background

SPE water electrolysis technology overview

The heart of the SPE water electrolyzer is the electrolysis cell which consists of an ion-exchange membrane with Teflon®-bonded, finely divided metal electrodes. Figure 1 shows this arrangement along with the water electrolysis reactions. Since the

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Elsevier Sequoia
SSDI 0378-7753(93)01779-H

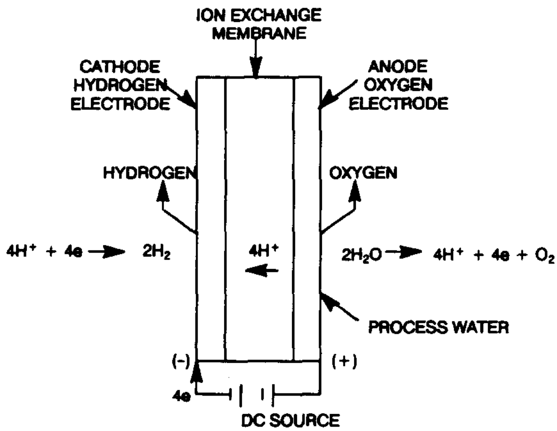

Fig. 1. SPE water electrolyzer reactions.

fixed acid ion exchange membrane has neither a traditional bubble point nor free electrolyte, operating pressures and hydrogen/oxygen differentials are limited only by the surrounding structures. This affords a significant safety factor in maintaining positive separation of the hydrogen and oxygen products.

The introduction of the perfluorocarbon cation-exchange membrane in the late 1960s enabled the development of the SPE electrolyzer. In prior years, water electrolyzers made with existing ion-exchange membranes had useful lifetimes of only a few hundred hours. With the use of perfluorocarbon ion-exchange membranes, the SPE water electrolyzer cell life has been demonstrated to be in excess of 14 years and projected to over 30 years depending on operating conditions.

In most practical applications, a number of cells are stacked in a filter press arrangement with as many as 100 cells electrically connected in series while the fluids are passed through the cells in parallel. Without any free electrolyte, the parallel fluid flows can be conducted without fear of shunt currents inducing stray water electrolysis and its potentially deleterious result of product gas mixing. The purity of the product gases from SPE water electrolyzers is typically greater than 99.99%.

Nuclear submarine oxygen generators

The cell structures, developed during the 1970s for nuclear submarine oxygen generation, have a capability of operating continuously at up to 400 psi. Limited by stack compression and cell frame strength, pressures higher than 400 psi are obtained by placing the entire stack within a pressure vessel.

The nuclear submarine SPE oxygen generator cell structure is also limited to about 400 psi differential pressure between oxygen and hydrogen. The significance of this design limit is that a moderately complex pressure control system is employed at 3000 psi. The pressure control system maintains oxygen and hydrogen pressures within 400 psi even during a power loss depressurization.

Space station SPE propellant generator demonstrator

Under contract to NASA/JSC, a 3000-psi hydrogen/oxygen generator based on the Naval 0.23 ft^2 SPE water electrolyzer cell configuration was designed and delivered. The purpose was to demonstrate the feasibility of producing 3000 psi hydrogen and

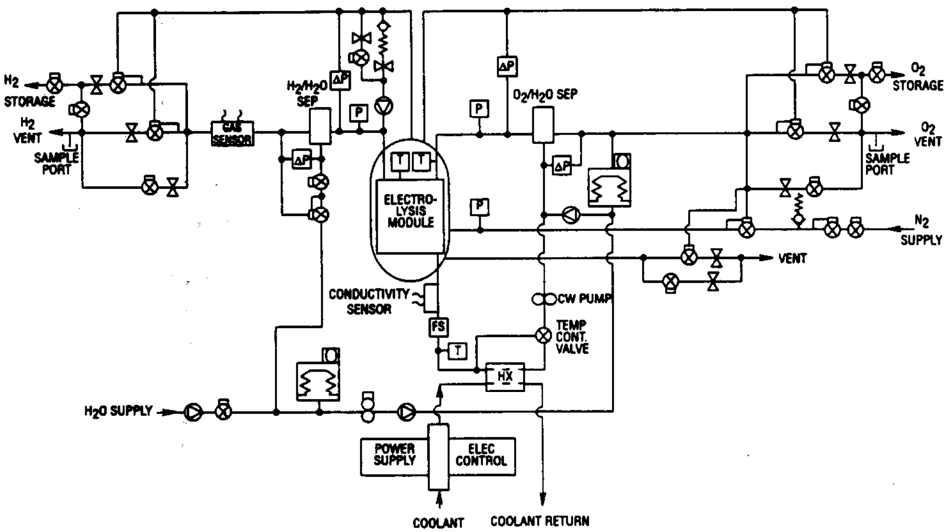

Fig. 2. SPE propellant generator system fluid schematic.

oxygen on-orbit for periodic rocket motor firing to maintain Space Station Freedom orbital altitude.

To reduce the mass and decrease the volume, as compared with the US Navy design, several configuration changes were made to the supporting pressure vessel and fluid manifold. The resultant SPE propellant generator demonstrator is significantly smaller and lighter. In the SPE propellant generator demonstrator, the pressure vessel is two torispherical domes opposed on either side of a central fluid plate. This configuration has a rating of 4 pounds of water electrolyzed per hour; the dimensions are 13 inches across the domes and 13 inches in diameter at the dome flanges. The total weight of the cell stack for space station propulsion is 193 lb.

Although the weight of the pressure vessel for the SPE propellant generator is significantly reduced from the nuclear submarine SPE oxygen generator pressure vessel, the system complexity remains the same. Figure 2 describes the SPE propellant generator system fluid schematic. As shown in this Fig., the pressure vessel is charged with nitrogen gas. This gas is increased slowly while the system comes to pressure so as to prohibit any differential pressure from exceeding 400 psi. Both the product hydrogen and product oxygen are pressure regulated using the pressure vessel nitrogen as a reference. An elaborate array of regulators, valves and relief valves is required in each of the three gas systems to prevent any unsafe condition (i.e., no two simultaneous and independent failures will produce a safety hazard). Since the cells are only designed for 400 psi differential pressure, no two failures in the pressure control system can allow pressure differentials to exceed 400 psi.

The new SPE cell structure

In order to further reduce weight and simplify the high pressure SPE electrolyzer system pressure controls, a new SPE cell structure has been developed. This new cell structure requires no pressure vessel enclosure in order to operate at elevated pressures. Demonstrated characteristics of this new cell structure include:

- leak free at greater than 3000 psi internal pressure
- leak free at greater than 3000 psi oxygen chamber to hydrogen chamber differential pressure
- pressure capability demonstrated with advanced thin membranes
- over 30 000 operating cell hours demonstrated at 2000 psi differential pressure
- over 4000 operating hours on a single unit at 2000 psi differential pressure
- three cell stack operated at 2000 psi differential pressure

The basic construction materials for the new SPE cell structure are the same as used in the nuclear submarine SPE oxygen generator system. Therefore, from a material's comptability viewpoint, the maturity of over 10 million SPE cell hours in nuclear submarine applications is maintained.

As previously mentioned, the weight of the domed stack in the Space Station SPE propellant generator demonstrator is 193 lb. In using the new SPE cell structure the stack weight for the same total active cell area would be 30 lb. A minor volume improvement is also obtained by elimination of the pressure vessel and a reduction of the cell spacing from 7 cells per inch in the nuclear submarine design to 10 cells per inch in the new structure.

The new SPE cell structure produces improved electrolyzer efficiency by significantly reducing internal component electrical resistance in the nonmembrane components. Further, ionic conductivity is improved since the new SPE cell structure is compatible with new high performance thin membranes whereas the SPE nuclear submarine electrolyzer cell structure is not. Figure 3 shows the performance improvement obtained with the new SPE cell structure.

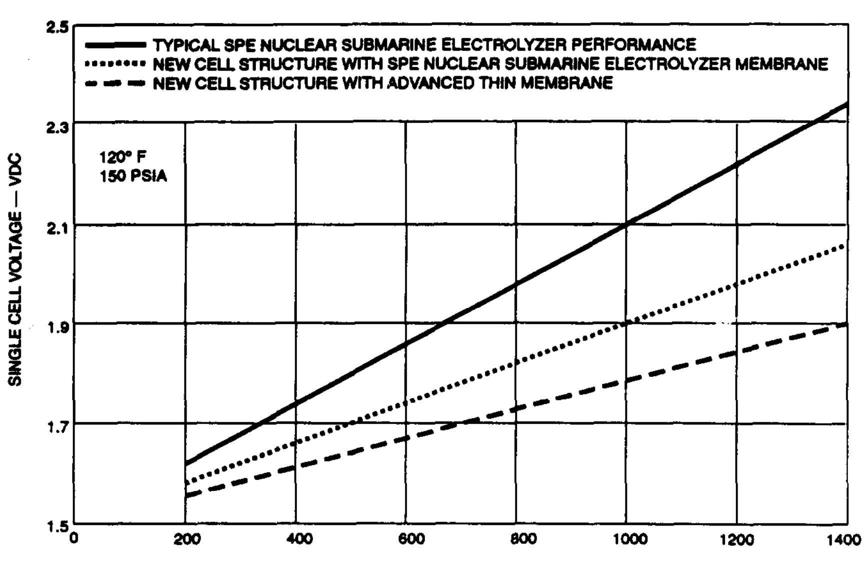

Fig. 3. Electrolyzer cell performance single-cell voltage vs. current density.

Systems impact from the new SPE cell structure

Apart from the afore-mentioned weight reductions from the new SPE cell structure, the simplification and reliability improvement in resultant systems is dramatic. In the case of the Space Station SPE propellant generator, the nitrogen subsystem would be altogether eliminated as would the array of regulators, valves and relief valves intended to maintain differential pressures below 400 psi. A high pressure SPE electrolyzer fluid schematic incorporating the characteristics of the new cell structure is shown in Fig. 4. This Fig. depicts the required SPE electrolyzer fluid schematic when it is desired to deliver both gaseous products at high pressure (i.e., high pressure hydrogen and oxygen for reboost propulsion or lunar base energy storage). Figure 4 fluid schematic can be compared with the previously displayed Fig. 2 to obtain a full appreciation of the components eliminated by virtue of using the new SPE cell structure.

Further simplification and reliability improvements and weight reductions are obtained if only one of the product gases is desired to be delivered at high pressure. In the nuclear submarine SPE oxygen generator cell design both product gases are produced at high pressure when only the oxygen is required to be at 3000 psi. The hydrogen, having been produced at ~3000 psi, is simply regulated down to its desired pressure level. The new SPE cell structure allows each product gas to be generated at its own desired pressure level.

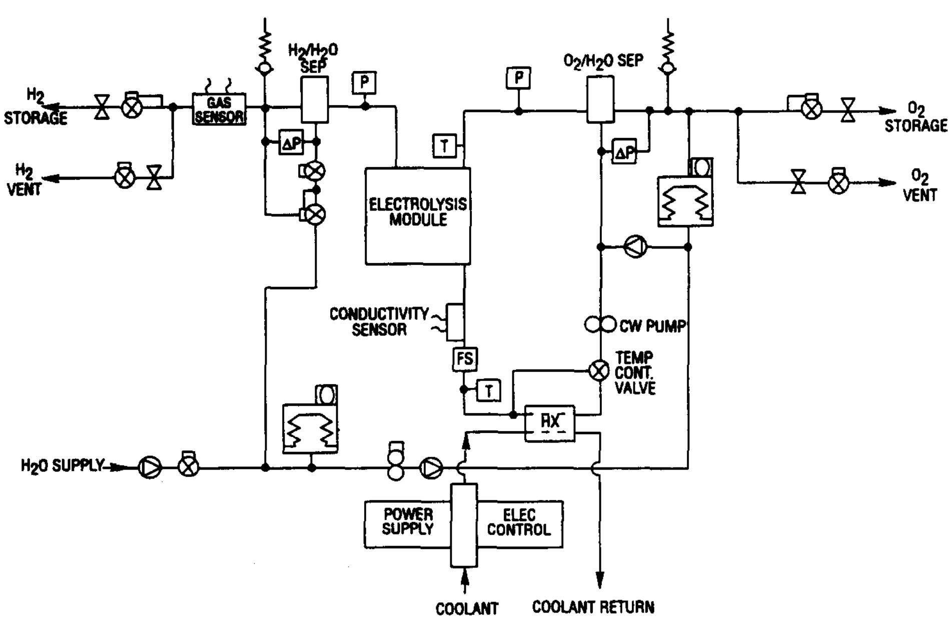

Fig. 4. High pressure SPE electrolyzer fluid schematic with the new cell structure.

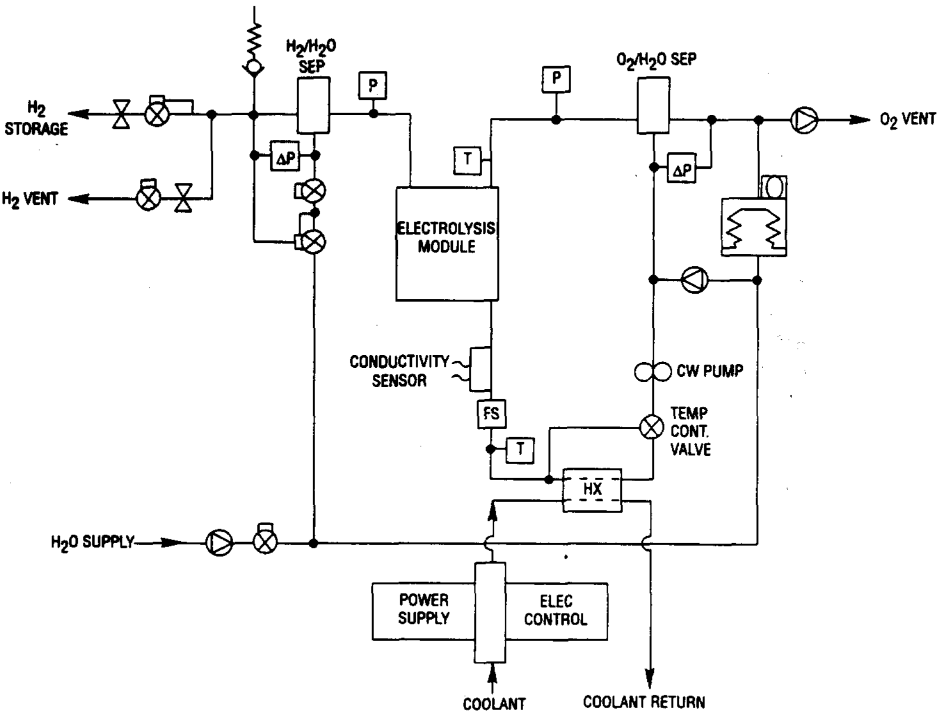

Fig. 5. High pressure hydrogen SPE electrolyzer fluid schematic with the new cell structure.

A lunar soil or material processing facility could require high pressure hydrogen from water electrolysis while the product oxygen was discharged to ambient for local metabolic purposes. Such an electrolyzer with the new SPE cell structure is shown in Fig. 5. The further improvements in this configuration include:

- the high pressure water feed pump is eliminated
- oxygen pressure regulation components are eliminated
- remaining oxygen system components can be designed for ambient pressure operation at a significantly reduced weight
- additionally, the high pressure hydrogen/ambient pressure oxygen configuration is more efficient due to reduced diffusion and the oxygen pressure Nernst effect.

The last possible configuration with the new SPE cell structure is an electrolyzer producing high pressure oxygen and ambient pressure or low pressure hydrogen. Such a configuration could be used to recharge spacesuit oxygen supplies while on orbit. Figure 6 shows the fluid schematic for high pressure oxygen and low pressure hydrogen. In this arrangement process water is introduced into the SPE electrolyzer through the hydrogen chambers of each cell. Because water must diffuse through the cell membranes to the oxygen anodes before the molecule is split into oxygen gas, electrons and protons, current densities are limited to a maximum of 500 A/ft^2. However, the very major advantage is the elimination of almost all of the high pressure components.

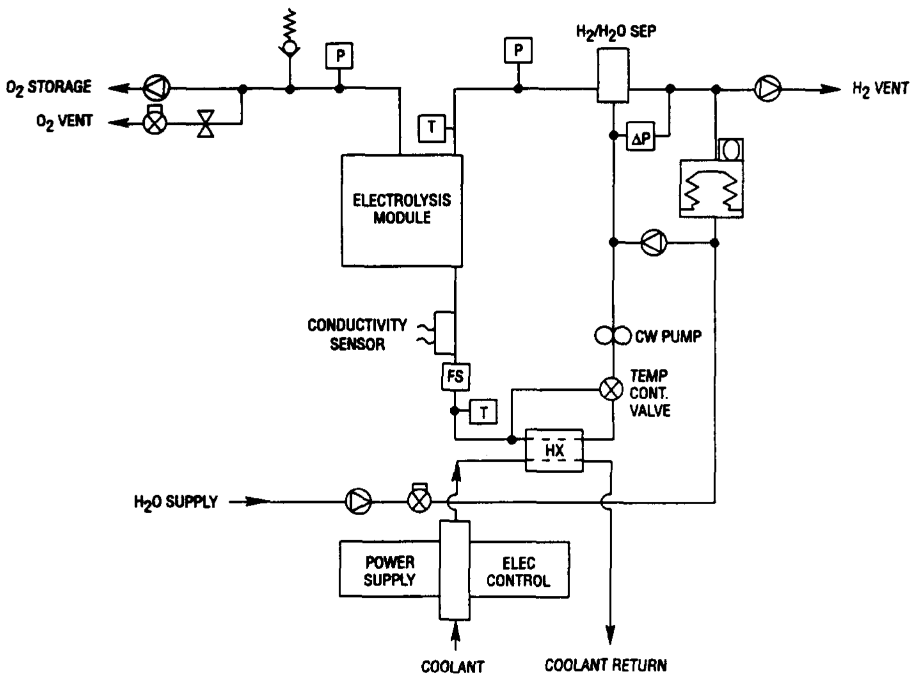

Fig. 6. High pressure oxygen SPE electrolyzer fluid schematic with the new cell structure.

Summary

The recently developed new SPE cell structure has allowed a much greater range of capabilities in the SPE electrolyzer product than with prior designs. Depending on the application, it is expected that the simpler system will result in reliability improvements by at least a doubling of mean time between failures; system weight reductions up to 50%; an improved efficiency or a doubling of current density at a constant efficiency, and last but not least, system costs significantly reduced.