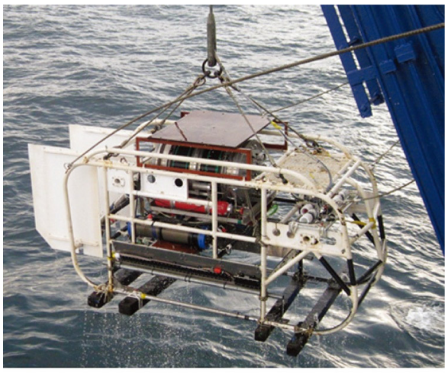
Development of Compact & High Efficiency Polymer Electrolyte Fuel Cell System for Enclosed Spaces



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In recent years, the need for undersea equipment for the utilization of ocean resources has been increasing. Responding to the advancement of devices and the lengthening of exploration periods, fuel cells are attracting attention as a power source capable of supplying electric power over an extended period of time, in contrast to conventional storage batteries, which don't have high power capacity. For use in undersea equipment, Mitsubishi Heavy Industries, Ltd. (MHI) has developed a new compact high-efficiency fuel cell system that employs a new structure in its gas circulation system and new fuel cells. This paper provides an overview of the new fuel cell system and presents MHI's development efforts.

1. Introduction

In 2000, MHI delivered the "Urashima" unmanned autonomous underwater vehicle to the Japan Marine Science and Technology Center (the present Japan Agency for Marine-Earth Science and Technology). Thereafter, the power source of the Urashima was replaced with a polymer electrolyte fuel cell system and the Urashima attained a continuous underwater cruise of 317 km, the world record for distance (**Figure 1**).[1] In this way, the capability of fuel cell systems for the extension of cruise range has already been demonstrated. In recent years, however, further improvement of efficiency, compactness, durability, and reliability of fuel cell systems is required due to the demand for high capacity power sources for undersea equipment responding to the advancement of devices such as sensors and the lengthening of exploration periods. To meet these needs, MHI has developed a new fuel cell system based on examinations of both fuel cell stacks and the entire system.

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Figure 1 External view of "Urashima" unmanned autonomous underwater vehicle[1]

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2. Overview of new fuel cell system

2.1 Problems with fuel cell systems for enclosed spaces

To supply electric power in enclosed spaces for a long time, a fuel cell is required to attain not only efficient use of the fuel, hydrogen and oxygen, as well as improvement of the power generation efficiency of the entire system, but also power reduction of auxiliary devices installed in the system and downsizing of the system itself. The fuel cell system installed in the Urashima needed a gas circulation device that recycled unreacted gas and a humidifier device that humidified the gas, resulting in problems such as a reduction of system efficiency due to the high power consumption of auxiliary devices and the impossibility of downsizing of the system.

However, both the gas circulation device and the humidifier device could not be eliminated because the former was necessary for the generation of gas flow for discharging water formed in the fuel cell system from the power generation portion, and the latter was required for performance improvement and durability retention of the catalyst and electrolyte membrane of the fuel cell.

In addition, a trace amount of hydrogen leakage was an issue for the use of the system in an enclosed space for a long time.

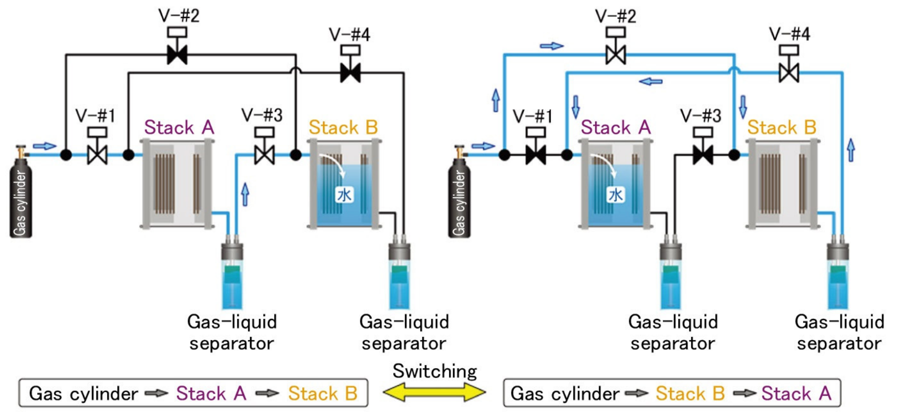
2.2 Operation of new fuel cell system

Figure 2 shows a gas system schematic diagram of the new fuel cell system developed for the elimination of the gas circulation device and the humidifier device. In this system, gas passes through one of the two fuel cell stacks (the upstream stack) and then flows into the other one (downstream stack). The functions of the upstream and downstream stacks are switched at set intervals by a valve.

In this operation, the gas needed for consumption in both the upstream and downstream stacks flows into the upstream stack. Water generated in the upstream stack is discharged by the flow of the gas because the gas needed for consumption in the downstream stack passes through the outlet of the upstream stack.

On the other hand, water generated in the downstream stack is accumulated because there is no gas flow during normal operation, but it is discharged by the gas flow that occurs when the valve is switched and the downstream stack turns into upstream stack.[1]

In this way, the switching of the valve serves in a manner similar to the conventional gas circulation device. In addition, water formed by the downstream stack is effective for humidification for the two stacks due to their periodical switching operation, and serves in a manner similar to the humidifier device. Therefore this system enables the establishment of a fuel cell system that has functions approximating gas circulation and humidifier devices, even when they are eliminated.



Operation of stack A

Position of stack A	V-#1	V-#2	V-#3	V-#4	Reaction gas	Generated water	Excess gas
Upstream	Opened	Closed	Opened	Closed	Supplied gas from gas cylinder (RH: 0%)	Discharged	Discharged
Downstream	Closed	Opened	Closed	Opened	Humidified gas (RH: approximately 100% (humidified at upstream stack))	Accumulates in stack	None (consumed fully)

RH%= Relative Humidity %

Figure 2 Gas system of new fuel cell system[1]

2.3 Fuel cell stack for realization of new fuel cell system

MHI has also been proceeding with the development of fuel cell stacks suitable for the new fuel cell system. Specifically, the channel shape of the gas distributing separator is optimized for stable power generation even at a low flow rate, and a sealing structure is employed for the overall stack in order to significantly reduce hydrogen leakage. In addition, the structure and material of the catalyst layer is optimized for the improvement of power generation efficiency. MHI is also working on improving the durability of the cell.

2.4 "Multi-Less" fuel cell system

As described above, the new fuel cell system enables high-efficiency, through the elimination of the gas circulation and humidifier devices (Blower-Less and Humidifier-Less) and a significant reduction of hydrogen leakage (Leak-Less). Accordingly, the system is known as the High Efficiency Multi-Less Fuel Cell System.

3. Development of elements for new fuel cell system

3.1 Improvement of performance and durability in fuel cell

Figure 3 shows the relationship between the electric current and the cell voltage to indicate the power generating performance of a fuel cell stack using cells in which the structure and material of the catalyst layer are optimized. Compared with the cell installed on the Urashima, the new system attains the improvement of power generating efficiency over the entire operation range (0 to 20 A) due to improvements such as the use of a high-activity catalyst.[1]

It is known that the polymer membrane of the fuel cell deteriorates significantly when the fuel cell is operated under low humidity. MHI considers the primary cause of polymer membrane deterioration to be hydroxyl radicals derived from hydrogen peroxide by-produced in electrode catalyst layers, and has developed unique long-life cells with radical scavenger layers that scavenge or stabilize hydroxyl radicals before they reach the polymer membrane (**Figure 4**).[2]

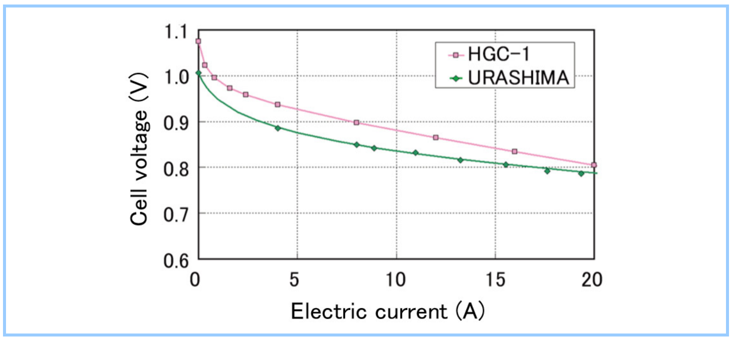


Figure 3 Power generation performance of cell (HGC-1) for new fuel cell system[1]

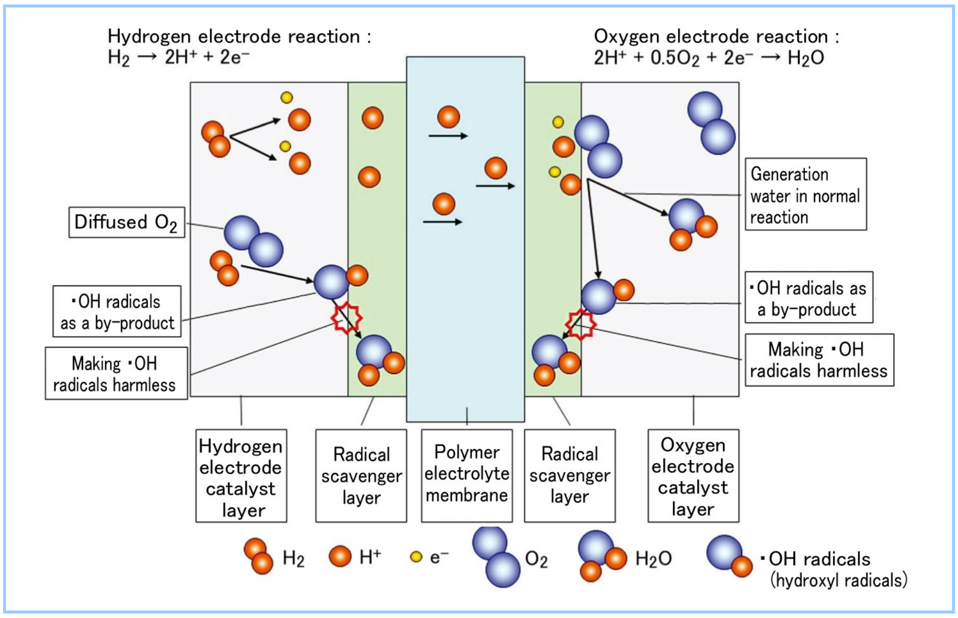


Figure 4 Schematic diagram of cell with radical collection layers[2]

Figure 5 compares the Accelerated durability test results of a standard cell and a cell with radical scavenger layers using rare earth carbonate. The horizontal and vertical axes of Figure 5 are the operation hours and cell voltage, respectively. In the test for the standard cell, failure occurred and continuous operation was made impossible after 16 starts/stops and 324 operation hours. The OCV (open circuit voltage) at that time was 0.85 V and the hydrogen concentration in the oxygen electrode outlet gas was 2.0 vol%. From this, it is presumed that the breakage of the polymer membranes led to hydrogen leakage resulting in the impossibility of continuous operation. In the test for the cell with radical scavenger collection layers, on the other hand, the power generation voltage drop from the initial state was relatively low, and operation could continue successfully even after 230 starts/stops and 5,000 operation hours. In addition, the high OCV value was retained and no increase of hydrogen concentration in the oxygen electrode outlet gas occurred. In this way, the suppression of polymer membrane deterioration could be confirmed.[3]

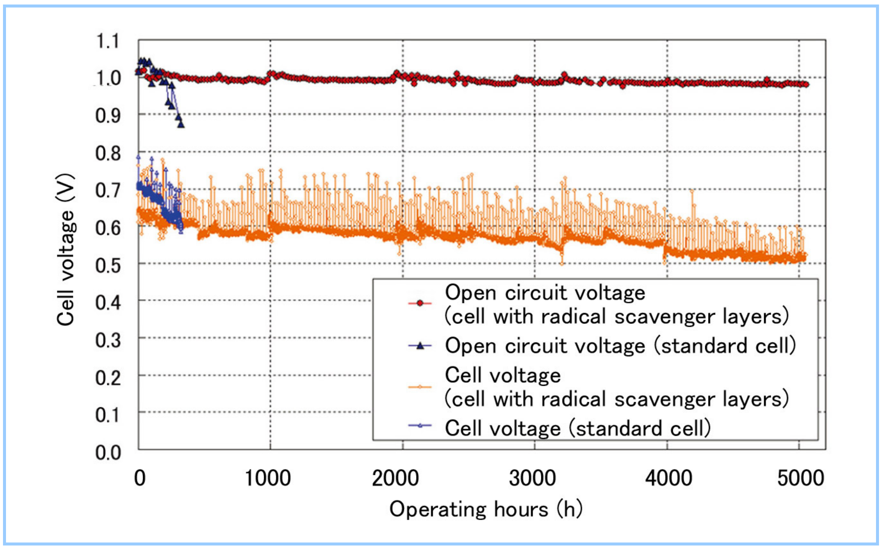


Figure 5 Accelerated durability test results of cell with radical scavenger layers[3]

3.2 Development of elements for new fuel cell system

Figure 6 shows the external view of the testing device for the element test of the new fuel cell system and the fuel cell stack.

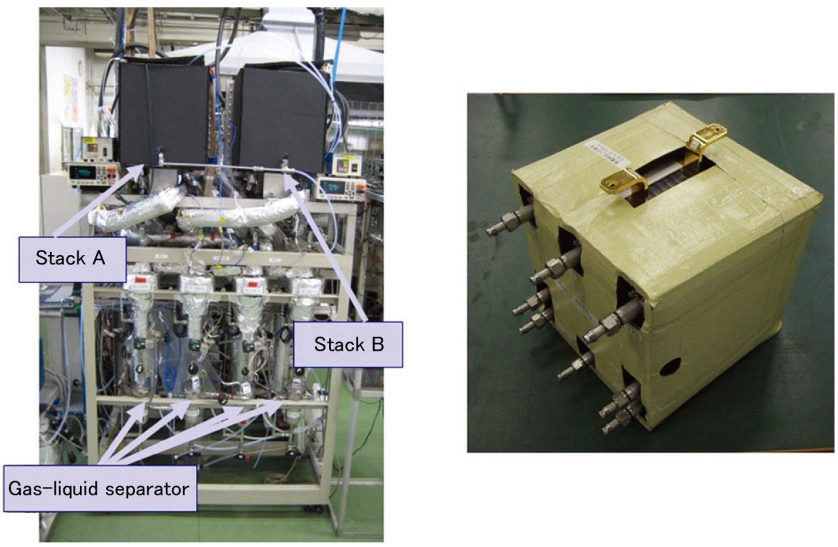


Figure 6 External view of testing device for element test of new fuel cell system and fuel cell stack[1]

Figure 7 shows the power generation of stack A in the testing device for the element test of the new fuel cell system. In Figure 7, the horizontal axis represents the operation hours and the vertical axis represents cell voltage, and the rectangular wave represents the switching of the valve. The cell voltage becomes a little bit higher when stack A is the upstream stack and a little bit lower when stack A is the downstream stack, but maintains a steady state on average. This demonstrates that power generation can be performed with each cell voltage maintained roughly equal.

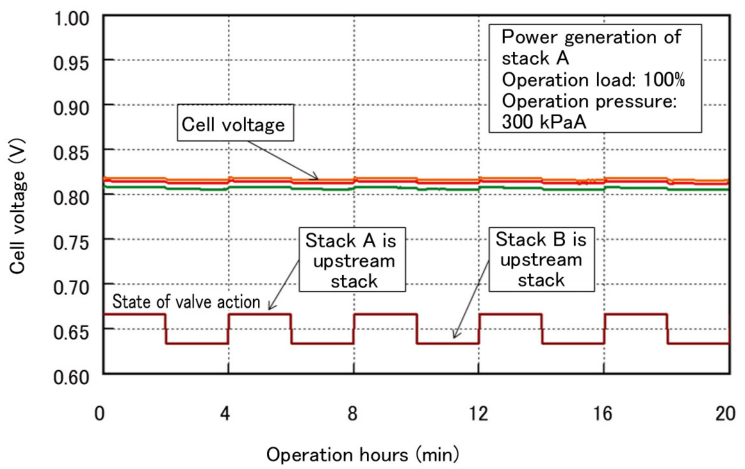


Figure 7 Power generation of stack A in testing device for element test of new fuel cell system[1]

Figure 8 shows the relationship between operation pressure, operation load, and power generation efficiency. When the operation pressure is increased from 200 kPaA to 400 kPaA, the power generation efficiency also increases from 53% (higher heating value, HHV) to 56% (HHV) at 100% load and from 61% (HHV) to 63% (HHV) at 20% load. This demonstrates that stable and high-efficiency power generation can be performed under various operational conditions.[1]

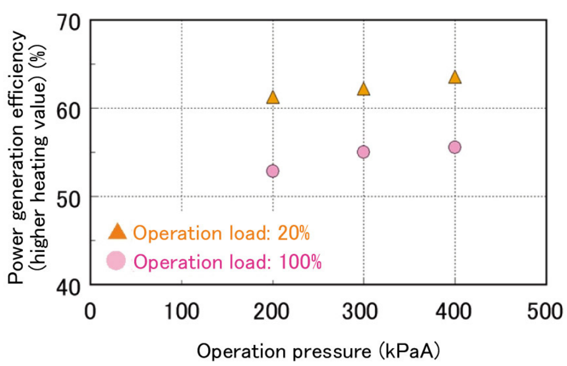


Figure 8 Relationship between operation pressure, operation load and power generation efficiency in testing device for element test of new fuel cell system[1]

In this way, the short-term performance of the new fuel cell system has been verified. The stability verification of long-term power generation was then performed. **Figure 9** shows the test results under the condition of 100% load and operation pressure of 400 kPaA. In this figure, the horizontal axis represents operation hours and the vertical axis represents power generation voltage. These test results demonstrate that stable power generation can be maintained for 1,000 hours.[1]

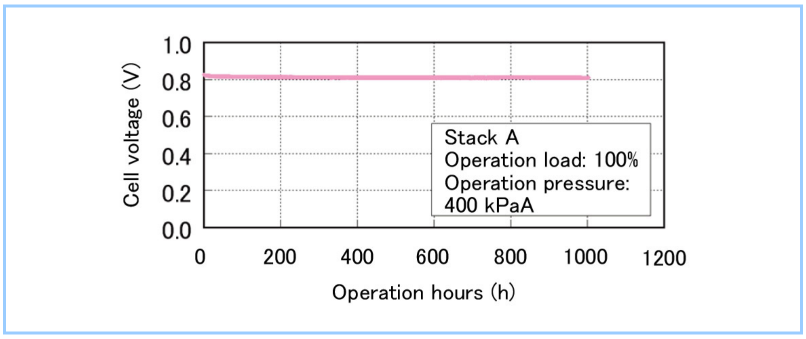


Figure 9 Verification result of long-term power generation stability in testing device for element test of new fuel cell system[1]

4. Progress of development and fabrication of new fuel cell system prototype

MHI has designed and fabricated a prototype of the new fuel cell system based on the development results of the elements. **Table 1** and **Figure 10** show target specifications and the external view of the prototype system, respectively.[4] In this prototype, 70% of the space for fuel cell power generation is occupied by reaction-related fuel cell components, and electric devices are installed in the remaining space. MHI has completed fabrication of the prototype and obtained data for the evaluation of its power generation efficiency, reliability, operability, durability and other factors, in land and underwater tests, and is proceeding with discovering the effectiveness and challenges of this system.[5]

Table 1 Specifications of new fuel cell system prototype[4]

Item	Specifications
Dimensions	Φ600 x 900 mm (Inside dimensions except for fuel tank)
Weight	200 kg or lighter
Power generation output	300 W (representative point)
Electric voltage	24 V (equipped with DC-DC converter)
Operation	Capable of stand-alone operation (system monitoring is needed) Nitrogen purge during stopping is unnecessary
Start	Quick start with a single touch

Data courtesy of JAMSTEC

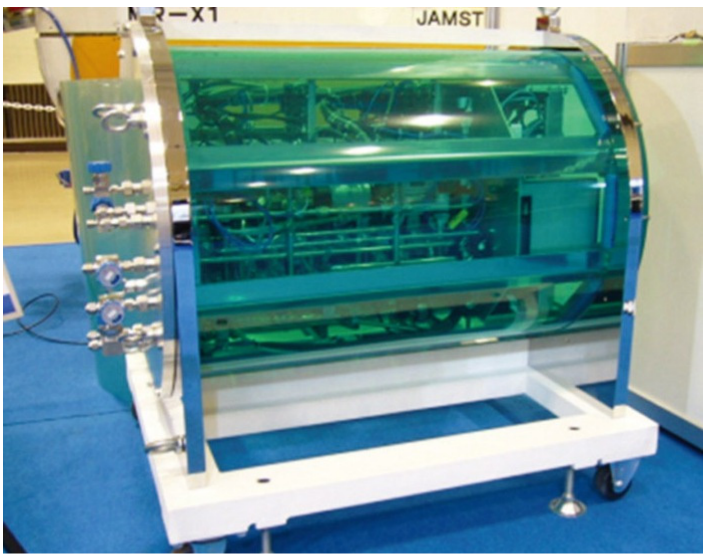


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Figure 10 External view of new fuel cell system prototype[4]

5. Conclusion

This paper has presented the features and development progress of MHI's new fuel cell system. MHI aims to contribute to improvement in efficiency and the accuracy of exploration through the realization of a small, highly reliable and high-efficiency fuel cell system for enclosed spaces that enables longer-term operation of deep-seabed exploration equipment and underwater vehicles. This system is also expected to significantly reduce operational costs. The system can also be used as a power source not only under the sea, but also in enclosed environments such as aerospace applications, clean rooms, shelters.[6] MHI will make efforts for the establishment of even easier to use fuel cell systems in the future.

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