PORTABLE SOFC GENERATOR WITH INNOVATIVE SPIROCELLs

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ABSTRACT

The innovative, patented solid oxide fuel cell design (trademark SPIROCELL®) presented at the 5th European SOFC Forum in Lucerne (1) will soon be integrated into a portable SOFC system of equally innovative appearance. SPIROCELL stacks of high volumetric (close to 1 kW/liter) and gravimetric (close to 1 kW/kg) power density will be used to energize a portable generator expected to deliver up to 1 kW (depending on operating temperature) at 24 VDC. Because of the extreme simplicity of cells, stack and system and because of the relatively low temperature of operation (600 to 700°C), the generator can be packaged in a bucket-size shell. Its total weight will be less than 10 kg. The generator will be capable of running on methanol and ethanol, perhaps also on propane or butane. The cost of fabrication is greatly reduced by simplicity of components and system design. The portable SOFC generator should be cost-competitive with conventional portable power sources, but it offers advantages with respect to noise, exhaust pollution and maintenance. Initial system experiments are scheduled for early 2003.

INTRODUCTION

For many years, the development of portable SOFC devices has been the key area of interest to the author. The first such approach was disclosed in 1994 (2), but for lack of funding the project was terminated. The second version of a portable 1 kW SOFC generator is now under development. It is designed to run initially on methanol or propane. There are many applications for such DC power sources, in particular, as the basic design can be adapted to run on biogas, natural gas or even vaporized liquid hydrocarbons. To make such a small power generator truly "portable", its weight should not exceed the weight of a bucket of water or 10 kg.

Also, portable devices must be small in volume. Again, the bucket provides a good reference geometry for our design. If the thickness of the thermal insulation jacket is subtracted from the outer bucket perimeter, about 120 to 150 mm are left for the diameter of a cylindrical stack. Similarly, the stack should not be taller than 100 mm to fit the typical bucket height.

Furthermore, for rapid start-up the stack operating temperature must be low. Also, the thermal inertia, i.e. the stack mass of the portable SOFC generator must be minimized.
The target numbers of 1 kW/kg at 1 kW/liter require that the average weight of 1 cm³ stack volume is 1 gm and that 1 W of power must be generated within this cube. This can only be accomplished by a compact ceramic-metal hybrid cell design and the use of advanced SOFC materials for low temperature operation.

Presently, SPIROCELLs of 130 mm diameter are used. Each cell is about 2 mm thick. A 50-cell stack is only 100 mm long. The two end plates add another 10 mm to the total stack height of 110 mm.

Each cell has an active area of about 90 cm². At the target power output of 220 mW/cm² the anticipated 1 kW of DC power should be obtainable. With more advanced LTSOFC materials (3) the design power output can be achieved with shorter stacks, or at lower operating temperatures.

Initially, the targeted cell life is 2,000 hours. This seems to be short compared to the 40,000 hours required for stationary applications. But the typical lifetime of portable generators is only about 500 hours. But the first generation of SPIROCELLs is designed for low-cost fabrication and easy stack replacement. About five minutes are needed to replace a defective stack in a cold system.

SPIROCELL® DESIGN

The footprint of the patented (US Patent No. 6,344,290, EP No. 0960448, other patents pending) SPIROCELL design is shown in Figure 1. The cells are of circular geometry with one hole in the center for the supply of fuel to the interior of each cell. The fuel gas is then evenly distributed over the entire active area by means of grooves of spiraling appearance, hence the trade name "SPIROCELL". In fact, the mathematical formula for the grooves is that of a convolute. Patent protection has been obtained for a wide range of channel geometries resembling this ideal curve.

Figure 1. Footprint of the patented SPIROCELL design.
Every fourth channel accepts fresh fuel from the cell interior and ducts it to the outer portion of the active cell. An equal number of channels connect to the outside to eject the anode exhaust from the active area into the stack periphery. The fuel passes from channel to channel through the porous substrate of the anode structure. Short dead-ended troughs are placed between supply channels and exhaust channels. The purpose of these troughs is to distribute the gas flow within the porous anode layer and to assure that the entire anode surface is evenly supplied with fuel.

![Schematic illustration of the fuel and air flow within a SPIROCELL.](image)

Figure 2. Schematic illustration of the fuel and air flow within a SPIROCELL.

A second set of holes (six in the present design) is arranged around the center. Air is supplied through these holes to the space between adjacent cells. The holes are formed by tube rivets connecting both sides of the cell. Consequently, the airflow is blocked from entering the cell interior. The air flowing outward over the cathodes surface is guided by the spiraling ridges, i.e. the positive deformation of the fuel channels stamped into the circular separator disk. The internal air manifold is formed by aligning the air holes during stacking. Figure 2 illustrates the flow of fuel and air through one cell and suggests how both media would be distributed within an assembled stack.

The anode space is sealed at the periphery to obtain high fuel utilization and to minimize the penetration of exhaust gases into the anode chamber. Anode exhaust can only escape through the small openings of the exit channels at high velocity and under controlled conditions. Unspent fuel and air combine in the region surrounding the cylindrical stack. Part of the resulting heat is used to preheat the reaction air. In the portable design the
remainder is lost to the environment, but waste heat utilization may be considered for stationary applications. Figure 3 shows a complete cell in its assembled state.

![Assembled SPIROCELL](image)

**Figure 3. Assembled SPIROCELL.**

The circular separator plate with its spiraling channels is covered by a thin porous substrate supporting the active SOFC layers. SPIROCELLS are designed to accept ceramic electrolyte-supported or anode-supported cells, as well as metal substrates with active layers deposited by physical, chemical or electrochemical processes.

The spiraling channels on the anode side of the separator plate appear as ridges on the cathode side. These ridges make electrical contact with the cathode of the next cell and serve as current collectors. The electrons removed from the fuel at the anode of one cell are passed through the conducting porous substrate and the metal of the separator plate via those ridges to the cathode of the next cell where they convert oxygen atoms to ions that carry the electric charge to the next anode.

**SPIROCELL® STACK DESIGN**

At present we work with cells of 130 mm (5") outside diameter, but larger diameters are possible. Each cell is less than 2 mm thick and designed to generate up to 20 W of power. A stack of 50 cells will produce 1 kW and be only 100 mm (4") tall.

The design of the stack is also innovative with patents applied for. The stack depicted in Figure 4 is loaded with 23 cells. The compact cylindrical stack portion is only 40 mm tall. Fuel is admitted to the cells at the cold end of the stack handle. Air is transferred into the six air ducts from a stack pedestal, a system component not shown here.
The cells are stacked between a base plate and an end plate of opposite polarity. Both plates are pressed against each other by a spring-loaded tie rod in the center of the stack. The spring is located at the cold end of the stack handle. The tie rod is also used to conduct the electric current from the hot end plate to the outside. As this tie rod is placed in a reducing atmosphere, contact maintenance in the hot stack environment poses no serious problems. The second polarity ("chassis ground") is taken from the tube surrounding the tie rod and connected to the base plate. Tube and tie rod are electrically isolated from each other. The two electrical connections are located at the cold end of the stack handle. These interesting design features are also protected by the SPIROCELL patents.

The problem of contact resistance at the interface between the metallic separator plate and both electrodes cannot be solved by design. The functioning of a SPIROCELL depends on the availability of suitable interconnect alloys, as it does for any ceramic-metal hybrid SOFC configuration. But we aim at low operating temperatures and will use materials specifically designed for SOFC applications (4).

![Figure 4. Mock-up stack with 23 cells. Stack height 40 mm without end plates.](image)

**EXPERIMENTAL VERIFICATION**

Full size SPIROCELLs, not small samples thereof, were tested following standard procedures. Single cells and two-cell stacks were placed between two plates resembling the end plates of the original stack design. Short stacks of up to five cells can be tested with this experimental arrangement. To assure controlled test temperatures, the cell test unit is operated inside an electric furnace.

Preheated dry hydrogen and air were supplied to the end plates and from there to the sample cells/stacks. The temperature and pressure of hydrogen and air were measured.
near the center of the end plates where the gases are admitted to the cell/stack. Solid metal rods of 6 mm diameter welded to the end plates serve to conduct the electric current to the cold environment at negligible ohmic losses. A Hewlett Packard Electronic Load 6060A was used to set the cell current, while the voltage was measured with a small voltmeter of good quality. A DC offset voltage source kept the electronic load in the recommended voltage range of operation.

The cells were fitted with 3YSZ electrolyte-supported tape-cast material from InDEC (5). Because of a mismatch of geometries only 50% of the possible active area was covered by active cell material.

**Figure 5.** Voltage-Current characteristic of a SPIROCELL loaded with 3YSZ-electrolyte-supported cells from InDEC (50 cm²) active area.

**Figure 6.** Power density vs. current density for a SPIROCELL loaded with 3YSZ-electrolyte-supported cells from InDEC (50 cm² active area).
The results obtained are presented in Figure 5 and Figure 6. The data were taken at operating temperatures of 600°C, 700°C, 800°C and 850°C. In all cases, dry hydrogen and air were used. The hydrogen flow rate was "modestly low" but not yet precisely measured. We now have mass flow controllers integrated into an automated date acquisition system.

The observed open circuit voltage is slightly above one volt. Also, the voltage-current characteristics follow straight lines, indicating that the system is functioning well. At higher operating temperatures currents of up to 20 A were drawn. The power density curves are perfect in shape, but low in amplitude. About 130 mW/cm² was observed at 850°C. This result is in good agreement with reference numbers provided by the supplier of the ceramic material. Apparently, the limits of the 3YSZ electrolyte-supported cells were reached.

SYSTEM DESIGN

The design of the portable SOFC system is equally innovative. It consists of a base plate, a stack and a hood with integrated heat exchangers. Heat is transferred from the hot exhaust to the cold intake air. The system architecture is illustrated in Figure 7. This computer drawing does not show details of the control system or the small fan required to move the process air. As the unit is designed to work in remote locations, fuel and air flow will be controlled by mechanical devices. Nevertheless, an electronically controlled unit is also under development.

Figure 7. Design drawing of the portable 1 kW DC SOFC power generator.
NEXT STEPS

The SPIROCELL design has been licensed to the US Company Fucellco, Inc. with development activities in Switzerland. It is planned to use physical vapor deposition techniques for cell fabrication. The prototype of a 1 kW portable SOFC generator will become operable in 2003.

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