UBOCELL: 
AN INNOVATIVE SOFC DESIGN FOR SMALL-SCALE APPLICATIONS

Ulf Bossel
Fuel Cell Consultant
Baldeggstrasse 13
CH-5400 Baden / Switzerland

ABSTRACT

This is the first disclosure in Japan of the innovative "UBOCELL" (1) concept of a hybrid solid oxide fuel cell. This novel SOFC design may be applied to many small-scale applications such as portable generators (2) designed to convert natural gas, biogas, liquid gas and certain liquid hydrocarbons into 12 Volt DC power or small cogenerators used as domestic heat and power source. Also, the UBOCELL could be used with liquid fuels in automotive applications for onboard power generation or as main power source for hybrid electric vehicles.

THE UBOCELL DESIGN

The novel solid oxide fuel cell is a metal construction with floating planar ceramic PEN elements. Not the PEN, but the separator plate is the key element of the UBOCELL design. Consecutive separator plates form a stack matrix for the support of PEN plates. While in most SOFC designs the electrochemically active PEN layers are the dominating structures, they become subordinate, interchangeable elements in the UBOCELL design. In a floating arrangement the PENs rest between the two adjacent separator plates which provide fuel and air to the electrodes through permeable elastic cushions and soft current collector sheets. As a consequence, the PEN plates used in the UBOCELL need not be perfectly flat. Lateral extension of 0.5 mm can be tolerated.

World patents have been applied for the unique design illustrated in Figure 1. The fuel gas is admitted to the cold ends of the hollow separator plates. Conventional materials can therefore be used for the gas inlet seals. As the fuel flows inside the separator envelope towards the SOFC stack it is heated and reformed in the presence of catalyst material. The reformed fuel gases then leave the separator plate through a matrix of small openings so that the entire anode surface is uniformly exposed to fresh fuel. The air is ducted on the outside of the separator plate by a system of impressed groves. An optimized channel system ensures an effective removal of off-gases from both electrodes. No gas-tight seals are found in the hot zone, but a controlled leakage design was adopted. Energy losses across the perimeter of the 10 cm x 12 cm active area of the PEN elements are minimized by electrochemical means.
The ceramic electrolyte plates are suspended between flexible metal structures which collect the current on the anodes, conduct it around the separator plates and pass it on to the cathodes of the next PEN elements. These current collectors are pressed against the electrodes by gas-permeable elastic bodies. The electric current conduction scheme is shown in Figure 2.

The main features of the process-adapted UBOCELL design are:

- bipolar design, generally planar
- floating PEN plates
- flexible metal current collectors
- elastic element pressing current collectors against electrodes
- hollow separator plates for fuel gas distribution
- uniform fuel admission to the anode by a "gas showers"
- uniform air admission to the cathode by penetrating channels
- aerodynamic design of all fuel and air supply and exhaust channels
- use of conventional sealing materials at the cooled fuel inlet
- use of "electrochemical seals" in the hot environment
- partial reforming of hydrocarbon fuels inside the metal separator plate
- small thermal gradients.

The four key elements (separator plate, PEN, current collector, elastic cushion) can be mass-produced. They are easily assembled to stacks of desired size.

SEPARATOR PLATE

The separator plates consist two gently extruded sheet metal plates which are seam-welded around the perimeter so that hollow structures are formed. The topology of both plates is different to distribute the fuel gas within the separator plate from the fuel inlet opening to the matrix of small gas shower holes and to guide the air to the cathode and off-gases away from both electrodes. The total thickness of a the present separator plate is about 3 mm, but it could be further reduced in future.

The plates are made by shallow extrusion of 0.23 mm thick sheet of the high temperature Fe-Cr(19-21%)-Al (4.7-5.5%) alloy (German code 1.4767SE or DIN 17470, similar to UNS K 92400 or ASTM B 603 (IIB)). This material was developed for use in heating elements. It is not recommended for deep extrusions. At high temperatures an alumina layer is formed on the surface preventing further oxidation of the material. But this layer is also a perfect electrical insulator. The material can thus not be used for conventional bipolar plates.

The function of the separator plate is not only the distribution of fuel gas and air to anode and cathode, respectively, but it can be filled with catalytic material for the reforming of hydrocarbon fuels. For this option the fuel gas flow is shown in Figure 3.
CURRENT COLLECTOR

The separator being made from this common and inexpensive material cannot be operated as current conducting bipolar plate, but the electric currents must be conducted around the element by the current collector. Knitted sleeves of Ni (80%) Cr (20%) wire were fitted over the separator plate sandwiched between by two elastic cushions.

At high temperature this material worked well in the anode environment, but chromium oxide was formed on the air side which is only modestly conducting at 900°C. The resulting contact resistance proved too high for practical operation. Consequently, another commercial material, whose nature cannot be disclosed at this time, was chosen with reasonable success.

ELASTIC CUSHION

The elastic cushion has only a mechanical functions. It must be soft during assembly and start-up operation of the fuel cell. After the first excursion to operating temperatures, the cushion has adjusted to the irregularities of PEN, current collector or separator. It may then develop into a rigid sintered structure. But it must remain permeable to fuel and air.

Initially, ceramic fibre felt mats (Zirconia, Alumina) were used. But metal felts made of alloys similar to that of the separator plate gave better results.

ONE PRACTICAL APPLICATION

The main element of the UBOCELL design is the separator plate. The element was carefully designed and optimized. Tools were made for the design depicted in Figure 4 and over 300 elements were manufactured for system development under reproducible conditions.

As seen in Figure 5, the repeat elements consisting of the separator plate fitted with two elastic cushions and the current collector sleeve and the PEN plate are normally stacked horizontally with fuel being admitted at the cooler end which can be arranged below (Figure 5) or above (Figure 6) the active stack region. Presently, an SOFC DC generator for remote area applications is under development. It comprises a stack of 20 UBOCELL elements. The generator is designed for operation with liquid gas, selected liquid fuels, biogas, natural gas or hydrogen. The SOFC stack will be connected directly to a 12 Volt car battery which also serves as voltage stabilizer. Under design conditions each cell is operated at about 0.65 Volt.
A system schematic is presented in Figure 6. The stack is surrounded by the afterburner in the core of the multi-shell design. This placement ensures that operating temperatures around 800°C are maintained within the stack. Compact heat exchangers are used to transfer the heat of the hot exhaust to the incoming air which is preheated to about 120°C when passing through the void between the hot core and the cold outer shell.

A small 12 Volt blower is used to move the air. During start-up this blower is energized by the battery. It is powered directly once the cell has started to deliver electric energy.

The fuel conditioning system is placed in the hot region above the stack. Heat is recovered for vaporizing, preheating and pre-reforming liquid fuels. At the moment, partial oxidation is favored for the conditioning of hydrocarbons. The pre-reformed gas is admitted to the separator plate and then guided to the hot end for complete reforming. Heat generated in the afterburner is thus transferred to the fuel and utilized for raising the heating value of the reformed mixture admitted to the cells.

The DC-generator is started by burning fuel in the afterburner region surrounding the stack. Some heat is directly transferred to the stack while the remainder is exchanged with the incoming process air. The stack reaches temperatures of 700°C in a very short time and then begins to generate useful electric power. The operating temperature is held between 800 and 850°C. For a stack of 20 high-performance PENs the power output is expected to reach 0.7 kW equivalent to about 300 mW per cm² of active area.

**Figure 1: Schematic view of a UBOCELL repeat element**
Figure 2: Electric current flow within the UBOCELL design

Figure 3: Fuel gas flow within the separator plate
Figure 4: Design drawings both sides of the separator plate
Figure 5: Schematic drawing of the UBOCELL stack arrangement

Figure 6: Schematic of the 12 Volt DC SOFC Power Generator
REFERENCES

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