NOVEL SOFC TUBULAR DESIGN CONFIGURATIONS

Yanhai Du, Nigel M. Sammes, Ray England
Connecticut Global Fuel Cell Center
University of Connecticut
44 Weaver Road, Storrs, CT 06269-5233, USA

ABSTRACT

A novel tubular solid oxide fuel cell configuration with high volumetric power packing density is discussed. With good thermal shock resistance, high mechanical strength, easy sealing, and high volume manufacturing ability, tubular SOFC designs offer many advantages over planar designs. One shortcoming is the lower volumetric power packing density. As a result, for a given stack power, planar SOFC stacks will be smaller than tubular SOFC stacks. For a tubular design, tube size is one of the critical parameters to be determined. Small diameter tubes, less than 3 mm for example, will cause assembling problems due to the feasible nature of the tubes. The power of each cell is directly related to the cell active area. Obviously the bigger the tube, the larger the surface area results in more cell power. However, increasing the size in single tubular fuel cell will lead to lower power packing density and lower fuel utilization.

Multiple Tubular Fuel Cell design (MTFC) is a potential solution. MTFC design arranges a group of different sized tubular cells together as a basic module. One can assemble these basic modules to make a stack with high volumetric packing density. Comparing with a single tube design, the MTFC design increases volumetric packing power density by over 40% for a 2-tube assembly, over 80% for a 3-tube assembly, and 116% for a 5-tube assembly. MTFC design also increases the fuel utilization rate and the stack reliability. The module can be standardized and controlled individually. If one individual module fails, it can be switched off and replaced. This concept can be applied to any tubular design, for example electrolyte-, anode-, or cathode-supported designs. This concept of using MTFC design to increase volumetric power densities can also be extended to other type fuel cells.

BACKGROUND

Tubular solid oxide fuel cell (SOFC) designs have been shown to possess good thermal shock resistance, high mechanical strength, easy sealing, and high volume manufacturing ability. One shortcoming, compared with planar design, is the lower volumetric power packing density (1), resulting in a tubular stack being larger than a planar stack. For tubular design, tube size is one of the critical parameters to be determined. Small tubes, less than 3 mm for example, will cause difficulties for fuel cell stack assembly and production. On the other hand, as the power of each cell produces is directly related to the
cell active area, obviously the bigger the tube, the larger the surface area resulting in higher cell power, as shown in Figure 1. However, increasing the tube size will lead to lower power packing density and lower fuel utilization. The question is what is the optimized size of the tube and how to determine it.

A novel design of a tubular solid oxide fuel cell stack with high volumetric power packing density (VPPD) is needed. Multiple Tubular Fuel Cell (MTFC) design can potentially meet this need. MTFC design arranges a group of different size tubular cells together as a basic module. One can assemble numbers of the basic modules to make a stack with high volumetric packing density.

**VOLUMETRIC POWER PACKING DENSITY OF TUBULAR SOFCs**

The volumetric power packing density of a tubular fuel cell module (considering the diameter of the largest tube), \( P_v \), is a function of fuel cell performance and cell design, and it can be expressed in the following equation:

\[
P_v = \frac{4P_a n (d_i + \frac{n-1}{2} \Delta d)}{d_i + (n-1)\Delta d}
\]  

Where

- \( P_v \) = volumetric power packing density (VPPD), W/cm\(^3\), W/mL, or kW/L
- \( P_a \) = cell area power density, W/cm\(^2\)
- \( d_i \) = smallest tube ID, cm
- \( \Delta d \) = ID difference between the two neighboring tubes, cm
- \( n \) = number of tubes in a module

**EFFECT OF DESIGN PARAMETERS ON THE VOLUMETRIC POWER PACKING DENSITIES**

From Equation [1], it can be seen that four parameters will affect the volumetric power packing density. These are: (a) tube size \( d_i \), (b) tube size difference between the neighboring tubes \( \Delta d \), (c) the number of tubes in a module \( n \), and (d) cell area power density \( P_a \). The effect of each of these parameters on the VPPD is explained below.

**Tube Size**

For single tubular cell, as shown in Figure 1, increasing the tube size will increase power. However, this will result in a dramatic decrease in the volumetric packing power density. For example, if tube size is increased from 5 mm to 10 mm, the volumetric power density decreased by 50%. An increase from 5 mm to 15 mm decreases the volumetric power packing density by 67%.

**Number of Tubes Assembled for a Module**

As can be seen from Figure 2, increasing the number of tubes in a module will lead to an increase in power packing density. For example, for a module with \( d_i=10\) mm, \( \Delta d=2\) mm,
and \( P_e = 0.2 \text{ W/cm}^2 \), the power packing densities \( P_v \) are 0.628 kW/L for single tube \((n=1)\), 1.15 kW/L for \( n=2 \) \((P_v \text{ increases } 41\%)\), and 1.36 kW/L if \( n=5 \) \((P_v \text{ increases } 116\%)\).

**Distance or Tube Size Difference of the Neighboring Tubes**

Figure 2 also shows that for the same configuration (same \( d_t \) and \( n \)), decreasing the gap between the tubes will obviously increase the power packing density. For example, reducing \( Ad \) from 4 mm to 2 mm, will gain 30-40% more power for the same size module.

**Cell Performance**

Single cell performance (relative area power density \( P_a \)) is essential and directly influences the volumetric power packing density of a module or a stack.

**Fabrication**

The fabrication process of each individual cell may be the same as described in our previous work (2-4), where electrolyte or electrode support tubes could be fabricated using extrusion process, and the remaining cell components can be put on as thin films using various coating techniques. A schematic of this novel SOFC tubular design configurations is shown in Figure 3. The experimental work to prove this concept and techniques to collect the current from each individual cells are currently under investigation and the results will be reported.

**SUMMARY**

Overall, the Multiple Tubular Fuel Cell design can increase volumetric packing power density compared to single tube cell design. The critical size is about 7-8 mm. Smaller than 5 mm will cause high engineering and manufacturing costs. On the other hand if the tube size is bigger than 15 mm, low power packing density and larger stack size are the price. MTFC design has the potential to increase the fuel utilization rate as there are two reaction surfaces in contact with the gas. Since each module can be controlled and monitored separately, the modular design can help to increase the stack reliability. If an individual module fails, it can be switched off and replaced. This concept can be applied to any tubular SOFCs, such as electrolyte-, anode- or cathode-supported. The idea to increase packing densities can also be extended to other type fuel cell applications.

**REFERENCES**

1. S.C. Singhal, *Material Council 2002-2003 Institute Wide Seminar Series*, Georgia Institute of Technology, p. 25, (2002).
2. Yanhai Du, N.M. Sammes, submitted to *Ionics*, (2002).
3. Yanhai Du, N.M. Sammes, *Journal of the European Ceramic Society*, 21 (6), 727 (2001).
4. Yanhai Du, N.M. Sammes, and G.A. Tompsett, *Journal of the European Ceramic Society*, 20 (7), 959 (2000).
Figure 1. Power per tube and power packing density as a function of tube size for single tube configuration.

Figure 2. Volumetric power packing density as a function of tube size and design configurations.
Figure 3. Power per tube and power packing density as a function of tube size for single tube and multiple tube configurations.

Figure 4. Schematic of novel SOFC tubular design configurations.