High-efficiency hydrogen-air solid oxide fuel cell

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Introduction

Hydrogen is considered as the main energy carrier in the frame of hydrogen energy concept. A task of the most efficient transformation of the hydrogen chemical energy into electricity is very actual. It is accepted that low temperature fuel cells (alkaline and polymer electrolyte FCs) have the highest efficiency using hydrogen as fuel, whereas a solid oxide fuel cell (SOFC) is high efficient when using a hydrocarbon fuel. However it is possible to design the SOFC fed with hydrogen in such a way that its efficiency will be higher than that of the low temperature fuel cells.

Efficiency of the modern fuel cells

The fuel cell efficiency, η, is determines by average cells' voltage, U, fuel utilization, η_f, and type of fuel

$$\eta = \eta_f \cdot U/U_{tn},$$

where U_{tn} is thermoneutral voltage; for hydrogen, U_{tn} = 1,48 V (HHV). The fuel utilization in the low temperature fuel cells is near 1, the voltage values are from 0.6 to 0.8 V at 0,4 A/см^2 (see, for instance, [1, 2]). These voltage values correspond to the FC efficiency of 0.4 to 0.54. The fuel utilization in the conventional SOFC does not exceed 0.85, the voltage values are from 0.8 to 0.9 at the same current density (see, for instance, [3, 4]). Accordingly, SOFC efficiency is from 0.46 to 0.52 that is comparable with the efficiency of the low temperature fuel cells. Note that internal losses in the modern SOFCs are from 0.05 to 0.2 V at the current density above mentioned.

SOFC with hydrogen recycling

The SOFC efficiency can be considerably increased using a hydrogen recirculation in the SOFC system. The system comprises an electrochemical section (stack); a flow circuit for hydrogen recirculation including anode cells' channels, an ejector, a condenser, gas manifolds, and a heat exchanger; and an oxidant feeding system including cathode cells' channels, a blower, gas manifolds, and a heat exchanger (Figure 1). Hydrogen flow is supplied through the ejector into the gas manifold connected with the anode channels; the flow ejects an additional amount of hydrogen from the condenser where hydrogen is separated from steam of the mixture H_2 + H_2O outgoing the anode channel. As a result, the hydrogen concentration in the anode gas increases thus increasing the cells' electromotive force (EMF).

Figure 1. Conceptual diagram of the SOFC system with hydrogen recirculation "a" and "c" are anode and cathode channels, respectively;
HE is a heat exchanger; C is a condenser;
E is an ejector

Results and discussion

A ratio of an ejected flow to an ejecting one, under these conditions, is a recirculation ratio (RR). The RR increase leads to an increase in the cell's EMF values. Figure 2 illustrates the EMF distribution along a single cell (under the concept of Siemens-Westinghouse, as an example) at 1100 K for several RR values. It is obvious that the EMF increases essentially with increase in the recirculation ratio.

For practice, the average EMF value is of the most importance: a difference of this value and the internal losses is the average cells' voltage and allows calculating the SOFC efficiency. Shown in Figure 3 are dependences of the average EMF on the RR value plotted for a number of temperatures. The right axis in this diagram is the efficiency axis; the efficiency is calculated in an assumption that the internal losses are 0.1 V. It is apparent that the efficiency is higher than 60% even if the RR value is small and temperature is high. Development of the SOFC operating at moderate temperature is the main trend lately. In addition to the increase in the SOFC lifetime, the temperature decrease causes an increase in the EMF and hence in the efficiency. However the temperature decrease causes a decrease in the SOFC specific parameters. Consequently, the lower temperature, the larger the SOFC of the same power. Therefore, it is necessary to reach compromise between the SOFC size (that determines the capital cost) and the SOFC efficiency (that determines the current costs).

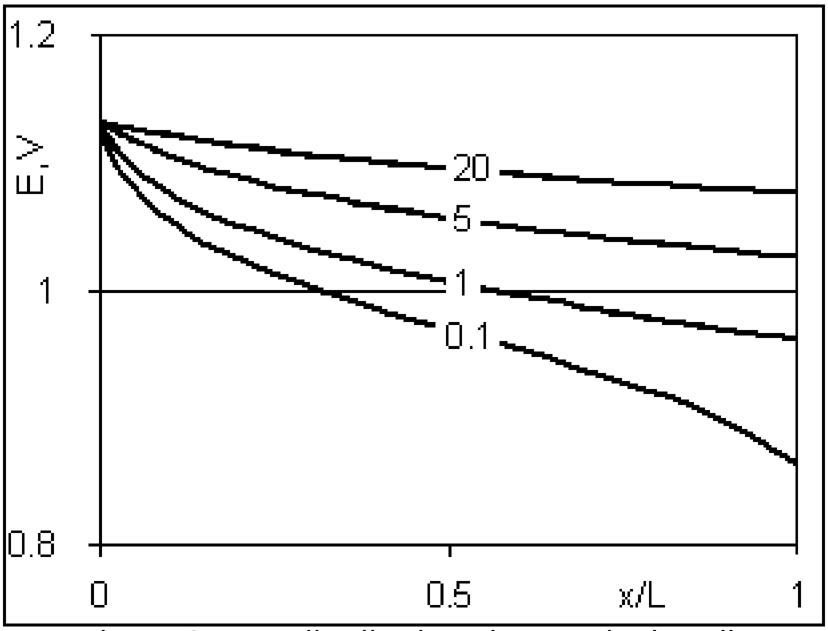

Figure 2. EMF distribution along a single cell.
Numbers on the curves denote the recirculation
ratio, x/L is the reduced length of the cel

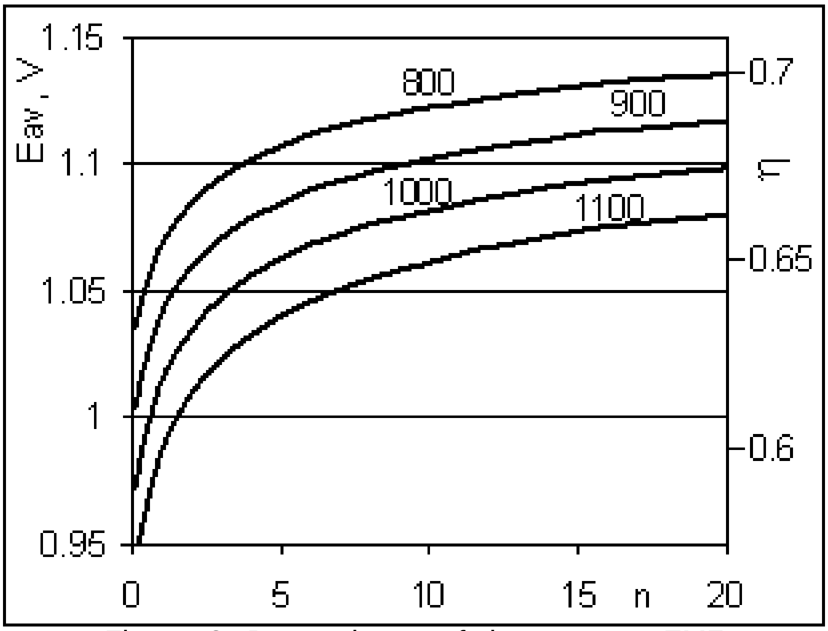

Figure 3. Dependence of the average EMF
and the SOFC efficiency on the recirculation ratio (n).
Numbers above the curves denote temperature in Kelvin

Conclusion

Solid oxide fuel cells have wide opportunity for utilization as the high efficient electrical generators using hydrogen as a fuel. Its efficiency can be significantly higher than that of known electrical generators.

References

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