APPLICATION OF SOFC FOR ELECTRIC VEHICLE

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ABSTRACT

Changing from gasoline powered vehicles to electric vehicles (EVs) will provide positive environmental effects. A present disadvantage of EVs with secondary battery systems is a short driving range. This can be improved by the application of a hybrid system of SOFCs and batteries. For that system, both tubular and planer types of SOFCs having 10kW power are designed which can be used for passenger cars with naphtha as fuel operated at 880~850°C. The tubular type has 106 l in volume and 100kg in weight, and were smaller and lighter than the planer type. Subjects to be investigated on SOFCs for EVs are described.
INTRODUCTION

The transport sector has an important impact on environment. The transport share of total oil use in OECD regions in 1990 is so high as 60%. According to the high energy consumption, the transport sector emits carbon dioxide (CO2), carbon monoxide (CO), volatile organic compounds (VOCS) and nitrogen oxides (NOx) in large volume. These emissions cause environmental problems at both local and global levels.

Electric vehicle (EV) is considered to be a candidate to solve those problems. Major advantages of EV are:
1. Low energy consumption
2. Low emissions of CO, NOx, VOCS and CO2
3. Low noise level
4. High fuel flexibility

At present, a battery system is the main driving source for EV. However, other systems such as a fuel cell or a solar cell can also be used.

A well designed compact car requires 5~10kW electric power.

Solar cells can generate about 100W/m² under insulation and the roof area of a compact car of 10m² provides the space for 1kW generation. This 1kW power is not enough to drive a compact car.

Here, we propose a compact passenger EV with a hybrid system of solid oxide fuel cells (SOFCs) and batteries. A fuel cell has the disadvantage of low instantaneous power generation. However, this disadvantage can be solved by the combination with a small battery system. And also this combination can increase the driving range.

Therefore we have selected the hybrid system of SOFCs and secondary batteries for EVs.

Table 1 shows estimated energy efficiencies of an internal combustion engine vehicle (ICEV), and EV with a battery system and hybrid system of SOFCs and batteries.
Table 1 Comparison of energy efficiencies of EVs and ICVE

|                     | ICEV | EV Battery | Hybrid of SOFC-battery |
|---------------------|------|------------|------------------------|
| Oil refine and transportation | 90%  | -          | -                      |
| Electric power generation       | -    | 40%        | 45%                    |
| Electricity transportation     | -    | 95         | -                      |
| Power Charge                   | -    | 85         | 85                     |
| Engine                          | 15   | -          | -                      |
| Mortar                          | -    | 80         | 80                     |
| Total efficiency                | 14   | 26         | 31                     |

As shown in Tab.1, the energy efficiency can considerably be improved by using hybrid system in an EV.

CONCEPTUAL DESIGN OF SOFC FOR EV

There are various types of fuel cells applicable for EV such as phosphoric acid fuel cell (PAFC), polymer electrolyte fuel cell (PEFC) and SOFC. Among these fuel cells, we have selected SOFC from the viewpoints of energy efficiency and fuel flexibility. Assumptions for the design of SOFCs are shown in Tab.2.

Table 2 Assumptions for Design of SOFC for EV

| Fuel                          | Naphtha (C_{6.8}H_{14.6}, ΔH_c=4580KJ/mol) |
|-------------------------------|--------------------------------------------|
| Operating temperature        | <850°C                                     |
| Power                         | 10kW                                       |
| Power density                 | 0.2W/cm²                                   |
| Voltage                       | 300V                                       |
| Utilization ratio of fuel     | 80%                                        |
| Total energy efficiency       | 45%                                        |
| Reformer                      | Internal reformer                          |

We have designed tubular and planar types of SOFC. And the results are presented below.
Tubular Type SOFC

We decided to apply small size tubes (outer diameter = 10mm, length = 220mm) which can be manufactured by current ceramic technology and have high thermal shock resistance. Fig.1 shows process flow of a total system and Fig.2 shows a tubular type cell module. The dimension of the container for main equipments is 440 × 550 × 436mm (106 l) including insulators of 40mm thickness. This volume is lower than an upper limit of about 200 l for the hybrid system including batteries. The total weight of the main components is about 100kg.

Planar Type SOFC

Fig.3 shows a planar type SOFC system. Its dimension is 590 × 590 × 490mm (170 l) including insulator and its weight is 200kg. The system volume of the planar type is 1.6 times higher than that of the tubular type and near the upper limit of the space for the hybrid system. Therefore, its volume should be reduced. The heat balance of the planar type system is shown in Fig.4.

FUTURE DEVELOPMENTS IN SOFC FOR EV

As described above, SOFCs can be used for passenger EVs in principle and remarkable improvement in environmental problems can be expected. However, there are many problems for the actual application of SOFC. Major points to be improved or investigated for EV are shown below.

Intermediate Operation Temperature

SOFC is usually designed to operate at 900~1000°C. This operating temperature is too high to use inexpensive metal parts. An operating temperature lower than 850°C, preferably 800°C, is desired. Numerous attempts to lower the operating temperature have been made and only partly succeeded 1)2). However,
Further investigation is needed for the development of reliable SOFC which can fulfil requirements of high energy density (>0.2W/cm²), high total energy efficiency (>45%) and high air utilization efficiency (>20%).

**Research and development items** are shown below.

**Electrolyte**
- Processing of thin YSZ film
- Application of supporting body system for electrolyte
- Hybridization of CeO₂ and YSZ films
- Development of new materials

**Cathode**
- Improvement of catalytic activity (addition of catalysts to LaMnOₓ or LaCoOₓ systems)
- Development of new cathode materials
- Optimization of microstructure

**Anode**
- Optimization of Ni/YSZ systems (composition, structure)
- Development of new materials (TiO₂/ZrO₂, metals)

**Interconnector**
- Processing of LaCrOₓ thin films
- Development of metal-high conductivity ceramics

Fundamental work such as measurements of basic properties of electrolytes, electrodes and interconnector, and clarification of reaction mechanisms on/in electrodes are also required.

**High Thermal Shock Resistance**

SOFC should be stable for a quick start-up and shut-down operation. It is possible to mitigate the thermal shock by warming SOFC during parking conditions. However, it is not feasible from the viewpoint of energy consumption. In order to increase the thermal shock resistance of SOFC, we must consider following items.
CONCLUSIONS

Hybrid systems of SOFCs and secondary batteries are useful for application in clean and energy efficient EVs.

Tubular and planar types of SOFCs having 10kW power were designed. The volume of the former system (107 l) was under the limit of space for it. The latter should be down-sized.

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Fig. 1 Process flow of total SOFC system

Fig. 2 10kW tubular type SOFC module
Fig. 3 10kW planar type SOFC system

Fig. 4 Heat balance of planar type SOFC system