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NEW HONEYCOMB TYPE SOFC FOR QUICK START OPERATION

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1．ABSTRACT

A honeycomb type SOFC using lanthanum gallate (LSGM), scandium stabilized zirconia (ScSZ) as electrolyte for quick start operation within one(1) minute, that has not been achieved ever, is under development. Honeycomb cells consist of fuel electrodes, air electrodes and air-cooling paths are arranged symmetrically with each other. Heat generated in the fuel electrodes is recovered by cooling-air, and delivered hot cooling-air is returned and induced into the air electrodes at the end of honeycomb. Reformed fuel by the reformers inserted inside of the fuel cells is returned to the opposite end of honeycomb and fed into the passage between the outer wall of reformers and inside wall of fuel electrodes.

As the heat, generated in the fuel electrode, is recovered effectively and is used for pre-heating of reaction air, a several kW-class honeycomb type SOFC of this new concept is expected to achieve the efficiency more than 50% and remarkable quick start operation.

2．INTRODUCTION

Rapid increase of world's energy consumption and demands for various mobile type of power sources will require the power sources be more efficient, compact and having quick start operation, especially for the use of mobile and distributed power supply systems.

Although Solid Oxide Fuel Cells(SOFC) has the highest efficiency in theory in all types of fuel cells, it has been considered not suitable for smaller size or mobile type power source, because of its high operating temperature and weakness against thermal stress caused by transient temperature changes.

Recently, an electrolyte such as scandium stabilized zirconia(ScSZ) and lanthanum gallate(LSGM), that works at more lower temperature than yttorium stabilized zirconia(YSZ), has been invented, and flexible design in structure becoming possible by using heat-resistant metals.

As the honeycomb is a structure having maximum surface aria and minimum heat capacity per weight, a highly efficient and compact honeycomb type SOFC having quick start ability will be realized with combined functions of compact heat exchanger and fuel cells.

As honeycomb type SOFC with new concept invented by the auther(s) is under development, aiming at the target of quick start operation within one(1) minute and efficiency over 50% .

3.CONSTRUCTIONS AND FUNCTIONS

Solid figure of the new honeycomb type SOFC is shown in FIG.1 and the outline is shown in FIG.2. The honeycomb type SOFC remarked as “Fuel Cell ” in FIG.1 is composed of fuel electrode cells, air electrode cells and cooling air paths. Each air electrode is arranged contacting with four sides to constitute a fuel cell with quadrangle section, and a cooling air path is arranged contacting with four corners to constitute a fuel cell. Thus, fuel electrode cells, air electrode cells and cooling air paths are arranged in order in a grid pattern respectively.

The air supplied from “Air Inlet & Outlet Unit” flows into the each cooling air paths through “Electrode & Insulation Unit”, and flows out at the end of honeycomb with cooling down the honeycomb wall and preheating the reaction air simultaneously. Discharged air from cooling air path with high temperature return in the “Reverse Chamber” and be fed to the air electrode cells as reaction air. The reaction air, flowing in the air electrode cells, supplies the O^{-} ion to the electrolyte and is discharged from “Electrode (+) & Insulation Unit” passing through “Fuel Inlet & Outlet Unit”.

The fuel, be fed into the inner reformers through Fuel Inlet & Outlet Unit, return at the opposite end of the honeycomb and flows into the reaction fuel paths between outer surface of the reformers and inner surface of the fuel cells. The fuel gas flowing down in the paths reacting with oxygen is discharged from Fuel Inlet & Outlet Unit passing through the Electrode (-) & Insulation Unit.

The honeycomb type SOFC with 500Watt capacity based on the new concept is composed of accumulated honeycombs on ten(10) stages in series as shown in FIG.2. Thus, higher voltage and lower electric resistance of the fuel cell are attained.

FIG.1 Fuel Cell Unit Overview

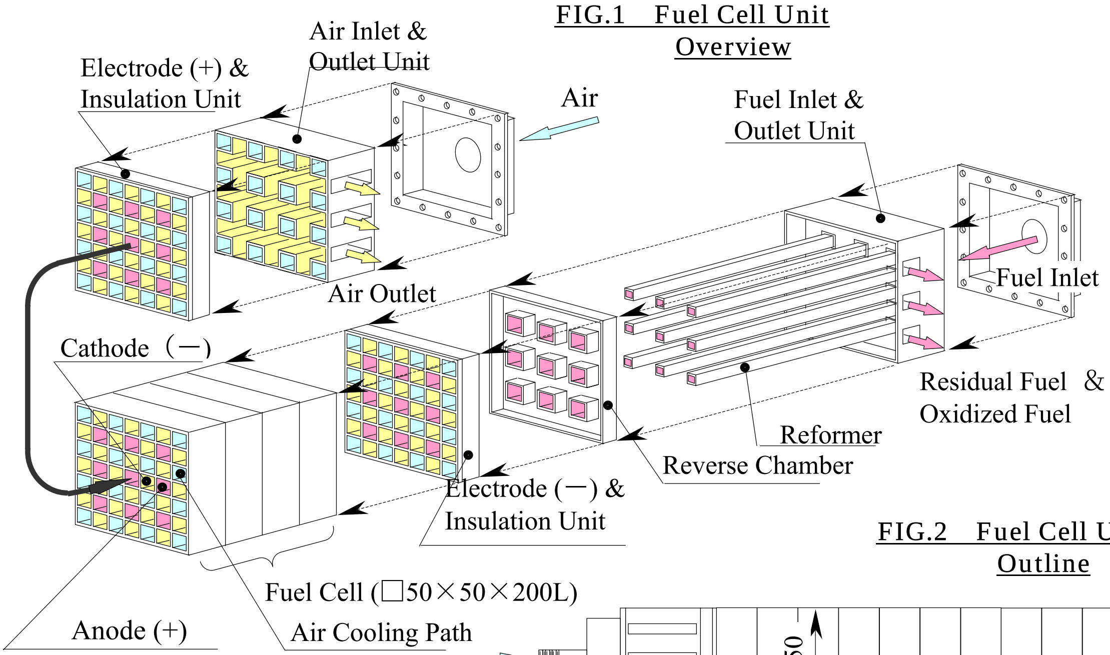
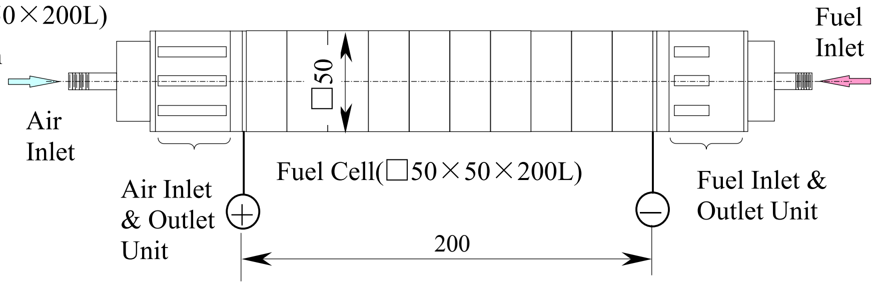


FIG.2 Fuel Cell Unit Outline



PRINCIPAL DATA OF 500W MODULE (TARGET OF DEVELOPMENT)

① Power Density	0.5 W/cm2 (500Watts/Unit)
② Size of Honeycomb Cell & Length	5mm×5mm×200mm
③ Wall Thickness of Honeycomb	0.5mm
④ Numbers of Cells per Unit Honeycomb	nine(9)lines×nine(9)rows (81cells)
⑤ Efficiency (HHV basis)	55%
⑥ O_2 Contents in Exhaust Gas	5.7%
⑦ Operation Temperature	800°C

4. ANLYSIS

(1) Conditions & Assumption of analysis

- Power Density : 0.4 W/cm2
- Size of Honeycomb : 5mm×5mm×200mm
- Thickness of Honeycomb Wall : 5mm
- Number of Cells : 7Lines x 7Raws(49Cells)
- Efficiency(HHV Base) : 55%
- Operation Temperature : 800℃

(2) Boundary of Analysis Model

Sectional view of honeycomb for analysis is shown in FIG.3. The geometric similarity portion was taken out for initial analysis. (FIG.4)

(3) Procedure of Analysis

① Establish Energy balance equation for the first element (i=0) using the model shown in FIG.4

② Calculate the equation to derive the unknown valuables of i=1 elements by matrix calculation method.

③ Feed that values into the equation developed for the i=1 element in the same manner to derive the values of that element.

④ Unknown Variables of i=1 element will be solved by matrix calculation method using calculated variables of i=0 element.

⑤ Hereafter, the same calculations are performed through the element of i=9.

As the element i=０ is the one where cooling air is returned and induced into the reaction air paths, cooling air outlet temp.($Tout3_0$) and reaction air inlet temp. ($Tin2_0$)are the equal value. In this analysis, it was selected at 800℃.

Next calculation following to i=0 element was carried out with the value that was replaced to $Tout3i_{+1}$ from Tin3i, and to $Tin2i_{+1}$ from Tout2i

(４) Solution

Based on the model for the analysis shown in FIG.3 and FIG.4, the following multiple liner equations are obtained.

$$Q1=Q2+Q3$$
$$Q4+Q3-Q5=0$$
$$\Delta T1-Q2/(G/2*Cp)+Q4/(G/2*Cp)=0$$
$$\Delta T2-2*Q5/(G*Cp)=0$$
$$Q2-\alpha 1*a1*TM1+\alpha 1*a1/2*\Delta T1=-\alpha 1*a1*T2in$$
$$Q3-\lambda*a2/b1*TM1+\lambda*a2/b1*TM2=0$$
$$Q4-\alpha 1*a1/2*\Delta T1+\alpha 1*a1*TM3=\alpha 1*a1*T2in$$
$$Q3-\lambda*a2/b1*TM2+\lambda*a2/b1*TM3=0$$
$$2*Q5-\alpha 2*2*a1*TM3-\alpha 2*a1*\Delta T2=-\alpha 2*2*a1*T3out$$

There are nine(9)unknown valuables (Q2, Q3, Q4, Q5, ⊿T1, ⊿T2, TM1, TM2, TM3) and nine(9) equations listed above, therefore the result can be derived.

In this analysis, the heat transfer between elements is assumed adiabatic, (i.e. heat transfer between elements does not exist) there would be certain amount of heat transfer between elements in the actual model. Therefore, expected more moderate temperature distribution than the result of this calculation.

Although this is a calculation model with relatively rough assumption, it is useful for the first step of evaluation that proves the possibility of the proposed new concept. A typical example of analysis based on the solution explained in this paper is shown in FIG.6.

Where heat transfer coefficients are α_1=0.5 cal/cm2・hr・℃, α2=1.0 cal/cm2・hr・℃, and temperature of reverse air chamber T3out and T2in are 800℃ for first element(i=0). Heat fluxes generated in fuel electrodes are same value(66.15 cal/hr) for all the elements.(From i=0 to i=9)

This analysis proves that the new concept of the honeycomb type SOFC for quick start operation could be realized and also provides the basic data to analyze more precise heat fluid dynamics and thermal stress analysis by FEM method.

① TM1 and TM3 being considered the mean temperature, the maximum temperature difference of honeycomb wall (TM1 and TM3:Max.⊿t=15℃) has possibility to cause relatively high local thermal stress, therefore quality control of electrolyte and structural design to release concentrated thermal stress is required.

② Because the heat capacity of cooling air, necessary for electro chemical reaction, is not sufficient to remove the heat generated and accumulated in the honeycomb, roughly two(2) times of theoretical air is required for cooling air.

③ To keep the temperature of electrolyte within the operable range, preheating of cooling air by exhaust gas is required.

FIG.3 Model for Analysis

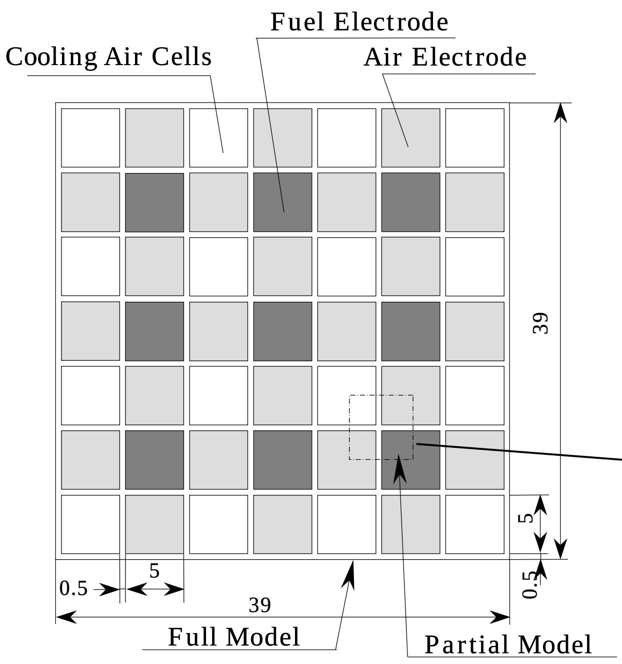


FIG.4 Variables and Heat Flow of Partial Model

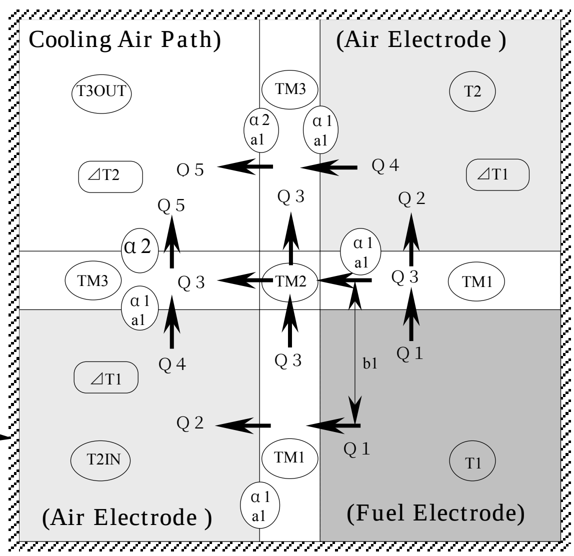


FIG.5 Marks and Relations of Initial Models(Longitudinal)

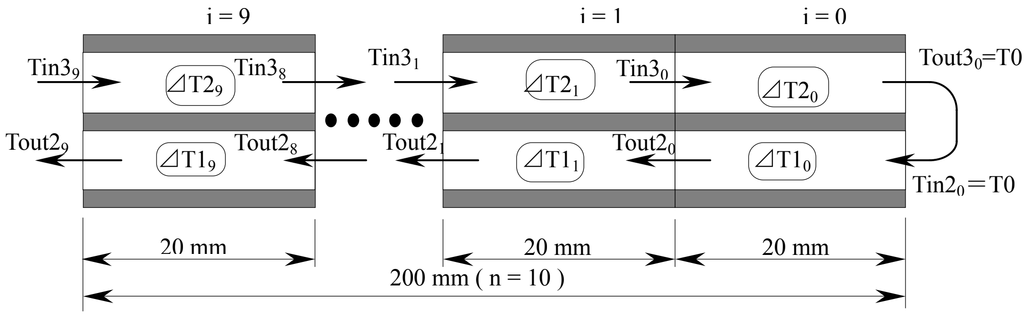


FIG.6 Typical Temperature Distribution of Honeycomb Type Regenarative SOFC
(T2in=800°C, α1=0.5cal/cm2・hr・K, α2=1.0cal/cm2・hr・K, λ=17.89cal/cm・hr・K)

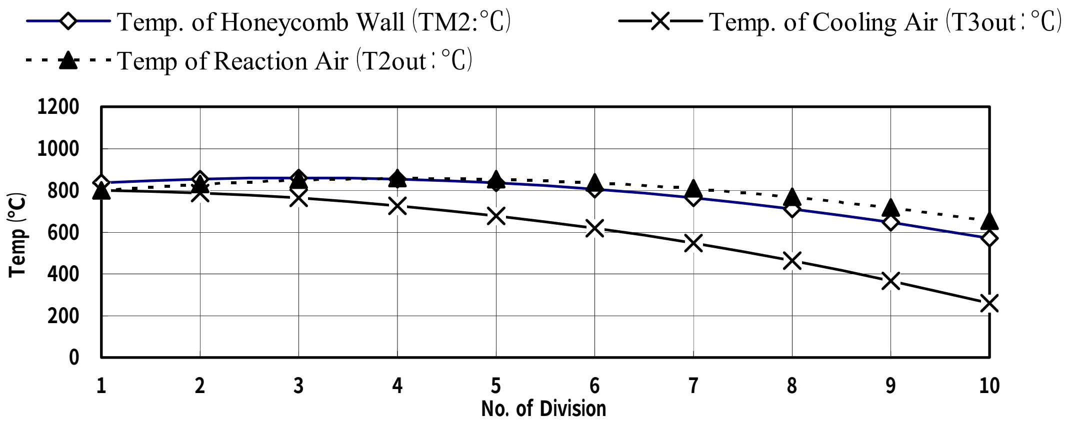
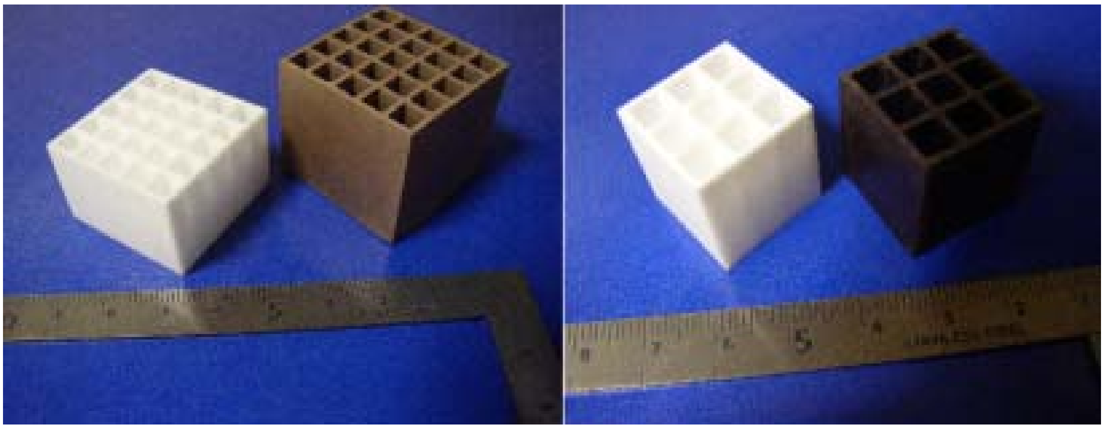


FIG.7 Trial Products of YSZ and LSGM Honeycombs
Five(5)lines×five(5)rows (Left) and Five(5)lines×five(5)rows (right)



5. Conclusion

The Structure of the new concept honeycomb type SOFC are shown and analysis was developed to examine its viability for future commercialization. To build up optimum design(structure) conditions, 3D heat flow and stress analysis is required based on the result obtained from this report, and we are now preparing for further experiment(analysis).

We are currently measuring the electromotive force of this honeycomb type SOFC using LSGM as its electrolyte at Ishihara Laboratory in Kyushu University. Also we are preparing for the verification at Yamazaki Laboratory in Tokyo Institute of Technology. Thinktank Phoenix is currently designing a demonstration unit , scheduled for completion in may 2005.

The honeycombs shown in the photos were made by YSZ and LSGM that will be used as the electrolyte of the demonstration unit.