

REDUCING TEMPERATURE DIFFERENCE OF A DIRECT AMMONIA TUBULAR SOFC TO 1K

Menglin Yang ¹, Fengli Liang ^{1, 2, 3*}, Zaixing Wang ¹, Junkui Mao ¹, Zhenzong He ^{1, 3}

¹College of Energy and Power Engineering, Nanjing University of Aeronautics and Astronautics,
Nanjing 210016, China

²Advanced Aviation Power Innovation Workstation, Beijing 101304, China

³Collaborative Innovation Center for Advanced Aero-Engine

*Corresponding author; E-mail: fengli0912@nuaa.edu.cn

In this study, a three-dimensional direct ammonia solid oxide fuel cell (DA-SOFC) was numerically modeled to investigate the effects of ammonia inlet flow velocity, tube structure, and catalyst filling on the internal temperature distribution of the cell. The results show that shortening the length of the ammonia inlet tube and increasing the inlet flow velocity leads to an increase in the temperature difference inside the cell. By perforating the ammonia inlet tube, the temperature difference can be further reduced, and the low-temperature zone inside the cell gradually decreases with the perforated area percentage increasing. In addition, placing ammonia decomposition catalyst inside the perforated inlet tube can further improve the temperature difference between the electrodes inside the cell, reducing it from 30 K to about 1 K. Furthermore, the temperature distribution pattern inside the fuel cell with metal supports was investigated, and it was found that the metal support can better export the heat generated inside the fuel cell. This study provides a new idea to improve the temperature distribution of DA-SOFC and enhance the stability and reliability of cell operation.

Key words: Solid oxide fuel cells; Direct ammonia; Three-dimensional numerical simulation; Ammonia inlet tube; Catalytic decomposition

1. Introduction

With the shortage of environmental resources and the environmental degradation caused by the massive use of fossil fuels, there is an urgent need to find new clean energy technologies. Solid oxide fuel cell (SOFC) is an efficient electrochemical power generation device that can directly convert the chemical energy of fuel into electricity without the limitation of Carnot cycle efficiency. Compared to conventional combustion-based power generation, SOFC is more environmentally friendly as they do not produce greenhouse gases or toxic gases during the power generation process [1]. Compared with proton exchange membrane fuel cell (PEMFC) operating at room temperature, SOFC operates in a higher operating temperature range (673-1273 K), which has many advantages, such as (1) low-cost electrode catalysts: low-cost electrode catalysts such as Ni, Fe, and other doped transition metal oxides can be used; (2) high outlet temperature and waste heat recovery utilization: SOFC has high outlet

temperature, the high utilization rate of waste heat recovery, and combined heat and power cycle can make its energy conversion efficiency as high as 80% or more; (3), wide fuel adaptability: the fuel is widely applicable, not only pure hydrogen but also methane (CH_4), propane (C_3H_8) and other low-carbon fuels can be used directly for SOFC power generation. Hydrogen is difficult to be widely used as a fuel for SOFC because of storage, transportation difficulties and safety issues [2]; methane, propane, and other low-carbon fuels are easy to store and transport, but their reforming temperature is higher and the reforming process produces CO, CO_2 and other polluting toxic gases [3-5].

Ammonia (NH_3), as a carbon-free fuel with high energy density itself, can be completely decomposed into H_2 and N_2 under the action of a catalyst, and the products are clean and pollution-free, which has a broad prospect as a fuel for SOFC [6-12]. In addition, ammonia is a renewable energy source and has been widely used in the chemical industry for many years. Besides, ammonia production and storage facilities have been basically perfected, and the current global production of ammonia exceeds 200 million tons/year of ammonia. Therefore, the study of DA-SOFC has important application significance [13]. The decomposition reaction of ammonia occurs inside the DA-SOFC, which is a heat-absorbing reaction, and the H_2 produced by the decomposition of ammonia is an exothermic reaction with oxygen, which causes big temperature differences inside the cell and decreases the cell's mechanical resistance [14-17].

A DA-SOFC with an iron-based catalyst and YSZ used as a composite anode was first reported by Wojcik et al. [18] in the UK in 2003, whose study showed that the cell performance was comparable to that of hydrogen as fuel when ammonia was introduced to the cell anode at 800-1000 °C. The results of Fournier et al. [19] showed that at 800 °C, the nickel-metal fuel electrode had the highest conversion of ammonia, which could reach 90%. Meng et al. [20] studied the performance of DA-SOFC and obtained a maximum power density of $3000 \text{ W} \cdot \text{m}^{-2}$ for DA-SOFC at 750 °C. In addition to experimental studies, many scholars have investigated DA-SOFC combined with numerical simulations.

Tan et al. [21] investigated the effect of the aspect ratio of planar ammonia-fueled SOFC on the performance of ammonia SOFC with the addition of an external ammonia pre-reformer, and showed that a higher aspect ratio allows the external reformer to better utilize the heat radiated from the cell for ammonia reforming. Masashi et al. [22] investigated both DA-SOFC and pre-reformed ammonia SOFC, and found that the DA-SOFC showed a lower performance and stability due to the uneven temperature distribution caused by the ammonia decomposition inside the fuel cells. This is because the pre-reformed ammonia SOFC has more even temperature distribution within the cell compared with the DA-SOFC. However, the external reforming of ammonia increases the complexity of the pre-reformed ammonia SOFC system. It is important to improve the uneven temperature distribution inside the DA-SOFC to improve the cell output performance and stability performance. Lai et al. [23] studied the internal temperature distribution of a DA-SOFC with open ends, and found that the excessive and rapid NH_3 decomposition reaction is the main cause of thermal shock in the DA-SOFC, and the temperature difference inside the fuel cell is as high as about 100 K. This temperature difference can affect the stability of the DA-SOFC operation, the thermal shock resistance of the cell (the ability of the material to withstand rapid temperature changes), and the output performance of the cell. The authors studied the optimization of the activation energy of ammonia decomposition and the adjustment of the pre-reformation of ammonia to minimize the temperature difference inside the cell, and their results showed that raising the energy barrier of ammonia decomposition reaction and the

pre-reformation of ammonia could enhance the thermal shock resistance of DA-SOFC. For DA-SOFC, the ammonia decomposition and H_2 oxidation reactions all occur on the anode surface, and there are both ammonia decomposition heat absorption reactions and hydrogen-oxygen reduction exothermic reactions on the anode at the same time, which lead to uneven temperature distribution inside the cell.

Hajimolana et al. [24] established a numerical calculation model for DA-SOFC and studied the variation law of the output voltage, cell temperature, and fuel cell efficiency under different design parameters such as tube diameter and cell length. In addition, Molla Asmare et al. [25,26] also studied the effect of the support form of DA-SOFC on the cell performance, and their results showed that the performance of anode-supported DA-SOFC was comparable to that of cathode-supported. Mustafa Ilbas et al. [27] studied the effect of the support form of DA-SOFC on the cell performance, and their results showed that compared to anode-supported SOFC and electrolyte-supported SOFC, the cell with cathode-supported structure has better performance, but neglected what effect the material of the support body would have on the cell temperature distribution. However, no researchers has considered that improve the temperature variation within the cell by changing the tubular cell's structure yet, for example, by inserting an ammonia inlet tube in the anode and optimizing the structure of the inlet tube.

To minimize the temperature difference inside the DA-SOFC, this paper presents a model of the temperature distribution in a fuel cell with a structure optimized ammonia injection tube, placing an ammonia decomposition catalyst inside the tube, and using metal support instead of traditional ceramic support. In this paper, a three-dimensional numerical simulation model of DA-SOFC was constructed by commercial software ANSYS Fluent, and the temperature distribution inside the DA-SOFC cell was investigated in this way. It focuses on some influent factors such as the structure of the ammonia inlet tube, ammonia inlet flow velocity, the loading of catalyst in the tube and the material type of the anode support et al. to get better temperature distribution inside the cell. Hopefully, this study provides some structural designs and theoretical supports for the development of the DA-SOFC technologies.

2. Model Description

2.1. Model assumptions

The following assumptions are made for the numerical model based on the ANSYS fluent simulation platform and the performance parameters of the SOFC:

- (1) SOFC operation process is at a steady state [5];
- (2) Consider the gas stream in the fuel and air passages as a laminar flow state [28];
- (3) The effect of ohmic heat on the thermal shock is neglected and the electrochemical reactions are considered to occur only at the electrode and electrolyte layer surfaces[29];
- (4) The model's gas obeys the equation of state of an ideal gas[30].

2.2. Geometric model

According to model assumptions and actual constructions of the fuel cell, a 3D model of the DA-SOFC is established in this thesis. Fig. 1 illustrates the central portion of the DA-SOFC geometric model. The relevant geometric parameters and model input parameters of the cell are displayed in Tab. 1 and Tab. 2. The model contains a cathode gas channel, anode gas channel, anode diffusion layer, cathode diffusion layer, anode collector, and cathode collector. Ammonia gas flows through the anode

gas channel and decomposes in the cell to produce hydrogen, which then participates in the electrochemical reaction. Air flows through the cathode gas channel, and hydrogen gas ionizes at the anode to produce hydrogen ions, which combine with oxygen ions produced by oxygen ionization at the cathode to produce water. The gas after participating in the reaction flows out of the respective channels.

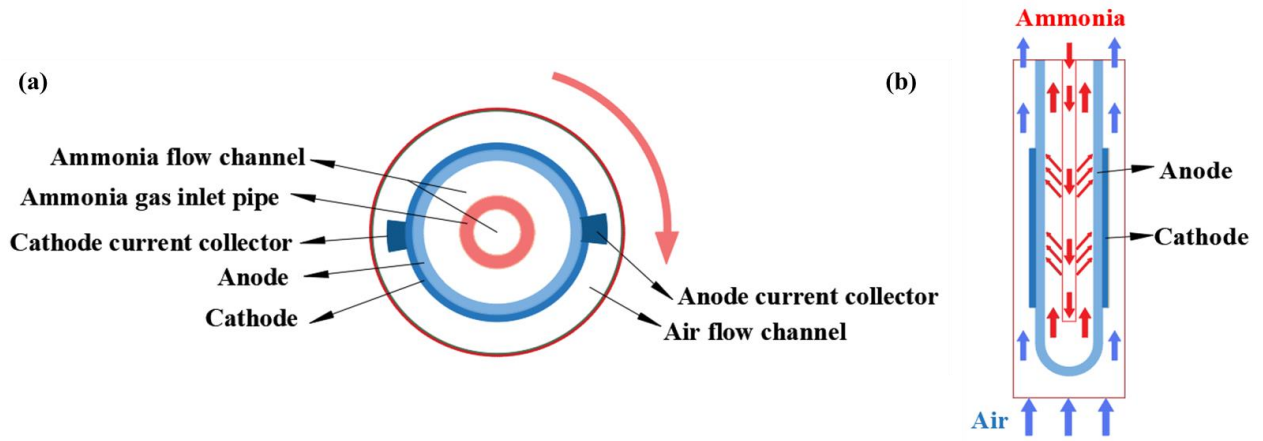


Fig. 1 Two-dimensional view of DA-SOFC

Tab. 1 Geometric parameters

Parameter Name	Value(mm)	Parameter Name	Value(mm)
Anode thickness	1	Anode inlet diameter	8
Cathode thickness	0.15	Single-cell length	130
Electrolyte thickness	0.02	—	—

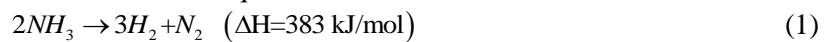
Tab. 2 SOFC model input parameters

Parameter Name	Parameter value
Gas inlet temperature (K)	1073
Work stress (Pa)	1.013×10^5
Electrode surface gas composition	
Anode: NH_3	100%
Cathode: O_2/N_2	21%/79%
Anode exchange current (A/m^2)	$1\text{e}8$
Cathode exchange current (A/m^2)	10000
Electrode porosity	0.4
Distortion	3

2.3.Numerical model

(1) Chemical and electrochemical reactions

The chemical reaction inside the DA-SOFC is mainly the ammonia decomposition reaction inside the cell, and the hydrogen gas produced by the decomposition further participates in the electrochemical reaction of the SOFC. The reaction equation is as follows:

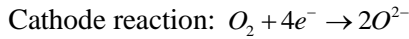


The reaction does not take into account the inhibition of ammonia decomposition by the products, and the rate of reaction is determined by the law of mass action $R_j(\text{kg}\cdot\text{m}^{-3}\text{s}^{-1})$.

$$R_j = K_j^f \prod_{i \in \text{react}} c_i^{-\gamma_{ij}} \quad (2)$$

where c_i is the molar concentration of reactants, γ_{ij} is the order of this reaction, and K_j^f is the reaction rate constant (influenced by factors such as operating temperature and the reaction's activation energy) [23].

The electrochemical reactions occurring within the SOFC are mainly redox reactions of hydrogen and oxygen ions in the vicinity of the electrolyte, and the reaction equation can be expressed as follows:



(4)

Three physical forces affect the potential difference: the Nernst potential, the Ohmic loss η_{ohmic} , and the activation loss η_{act} .

$$\delta V = N - \eta_{\text{ohmic}}(i) - \eta_{\text{act}}(i) \quad (5)$$

where i is the local current density, and the current density distribution of the cell at a certain voltage can be obtained by this relationship. Activated polarization occurs mainly at the two electrodes. It can be expressed via the Butler-Volmer equation:

$$i = i_0 \left[e^{(n\eta_{\text{act}}F/2RT)} - e^{(n\eta_{\text{act}}F/2RT)} \right] \quad (6)$$

$$i_0 = i_{0,\text{ref}} (Y_j)^\gamma$$

(7)

where i_0 stands for the exchange current density, and there are relations to the pressure and temperature of the reaction gas composition. $i_{0,\text{ref}}$ is the reference exchange current density, Y_j is the molar fraction, γ is the concentration index, n is the number of transferred electrons, and T is the cell operating temperature. As a result, both activation losses and concentration losses may be efficiently calculated [31].

The Butler-Volmer equation may be formulated in this way:

$$\eta_{\text{act}} = \frac{2RT}{nF} \sinh^{-1} \frac{i}{2i_0} \quad (8)$$

Ohmic polarization is related to the loss of ions that pass through the electrolyte, the porous electrode and the resistance of the conducting device.

$$\eta_{\text{ohmic}} = i \cdot R \quad (9)$$

where R is the resistance.

(2) Flow control equations

ANSYS fluent is used to simulate the SOFC, especially for (1) mass, momentum and energy transfer in fuel cell channels and porous electrodes; (2) current and potential field transfer in porous electrodes and solid conducting regions; (3) electrochemical reaction in the electrolyte/electrode/gas interface, ammonia decomposition reactions in the flow path.

Using the predefined ANSYS fluent multicomponent diffusion model and taking into account the volume diffusion coefficient of species i in a mixture, the impact of porosity on the diffusion of a multicomponent mass can be described as follows.:

$$D_{ij,\text{eff}} = \frac{\varphi}{\tau} D_{ij} \quad (10)$$

where τ is the curvature and ϕ is the porosity.

The solution of the conductivity problem is similar to the calculation of the heat transfer problem. Based on the principle of charge conservation, the potential field is calculated for the entire conductive region.

The solution of the conductivity problem is similar to the calculation of the heat transfer problem. Based on the principle of charge conservation, the potential field is calculated for the entire conducting region.

$$\nabla \cdot i = 0 \quad (11)$$

$$i = -\sigma \cdot \nabla \phi \quad (12)$$

where ϕ is the electric potential, σ is the conductivity. Therefore, the controlling equation of the electric field can be expressed as:

$$\nabla \cdot (\sigma \cdot \nabla \phi) = 0 \quad (13)$$

2.4. Model validation

To verify the reliability of the 3D tubular DA-SOFC numerical model established in this paper, the simulation results of this paper were compared with the experimental data of Luo Yu et al. [32]. The comparison of the current density curves of tubular DA-SOFC at cell working temperature of 800 °C and fuel inlet flow velocity of 100 ml/min is given. The comparison in Fig. 2 reveals that the error is within the allowable range of 10%, so the reliability of the model established in this paper can be verified.

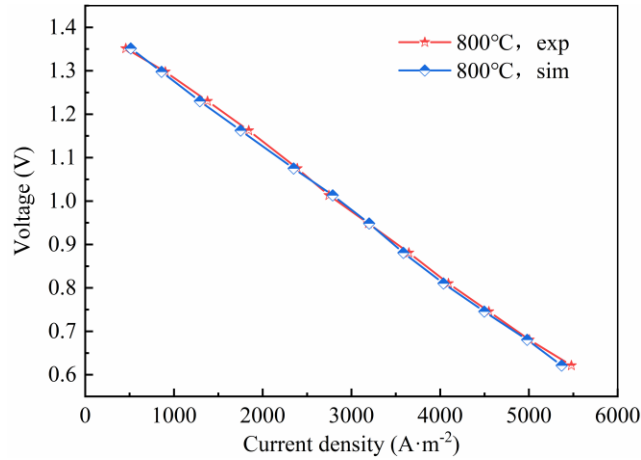


Fig. 2. Comparison graph of simulation results and experimental results

3. Results and discussions

3.1. Effect of inlet tube length on SOFC temperature

Fig. 3 shows the internal temperature distribution of DA-SOFC with different lengths of ammonia inlet tube structure. The simulation condition is that ammonia inlet temperature is 800 K and the cell operating voltage is 0.7 V. Besides, keep the ammonia inlet position consistent.

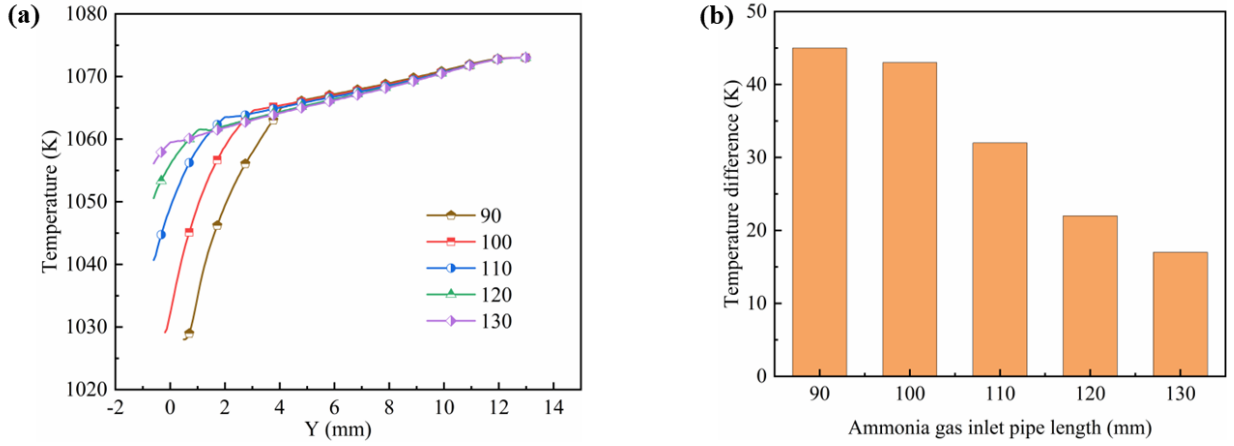


Fig. 3. (a)Temperature distribution curve in the tube, and (b) Temperature difference value of different inlet tube lengths

Fig. 3(a) shows the temperature distribution curves inside the 90 mm, 100 mm, 110 mm, 120 mm, and 130 mm ammonia inlet tube tubes. It can be seen that the temperature difference (the difference between the highest and lowest temperature) inside the cell is improved as the length of the ammonia inlet tube increases. The temperature variation of the fuel cell decreases from 45 K to 17 K when the ammonia inlet tube increases from 90 mm to 130 mm (as shown in Fig. 3(b)). In summary, the increase in the length of the ammonia inlet tube is beneficial to improve the temperature difference inside the fuel cell.

3.2. Effect of ammonia inlet flow velocity on SOFC temperature

Fig. 4 shows the influence of different ammonia inlet flow velocity on the temperature distribution inside the DA-SOFC in a cell model with a 130 mm ammonia inlet pipe. Temperature of ammonia inlet is 800 °C, and the fuel cell working voltage is 0.7 V.

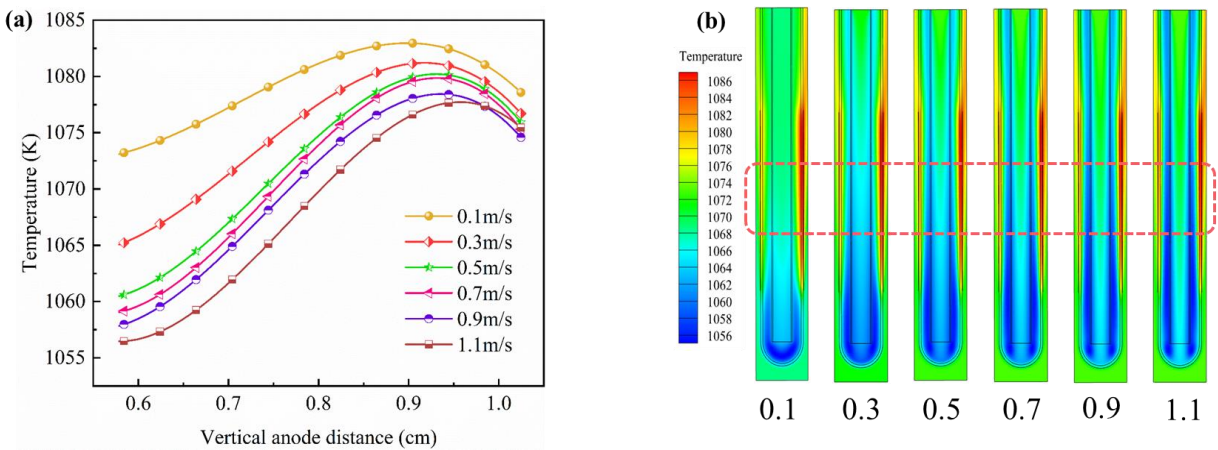


Fig. 4. (a)Temperature distribution curves of cell cross-section, and (b)Temperature distribution for different inlet flow velocity

As Fig. 4(a) illustrates the temperature distribution curve of a cross-section at a position of the cell under the ammonia flow velocity of 0.1 m/s, 0.3 m/s, 0.5 m/s, 0.7 m/s, 0.9 m/s, and 1.1 m/s, it can be found that the temperature variation of the cell cross-section gradually becomes larger with the raising of the ammonia inlet flow velocity. When the ammonia inlet flow velocity increases from 0.1 m/s to 1.1 m/s, the temperature difference in the cross-section of the cell increased from about 10 K to

about 20 K. This is because as the ammonia flow velocity increased, the ammonia flow velocity near the electrode side became fast. This will increase the decomposition reaction of ammonia on the anode of the cell and increase the temperature difference at the electrodes. The temperature distribution cloud in Fig. 4(b) also shows that with the increase of ammonia inlet flow velocity, the temperature of the flow channel near the anode side of the cell gradually decreases, and the temperature difference on the anode increases.

3.3. Influence of different structures of the inlet tube on the temperature of SOFC

Many research scholars have focused on the problem of uneven temperature distribution inside the DA-SOFC. They studied the mechanism of ammonia decomposition from the perspective of ammonia decomposition catalyst, but few scholars have focused on the effect of the structure of the ammonia inlet tube on the internal temperature distribution of SOFC. As shown in Fig. 5(a), three structural models of the anode inlet tube, perforated anode inlet tube (the size of the holes is the same, and the larger the perforated area, the greater the number of holes), and anode inlet tube with both perforated and placed ammonia decomposition catalyst were constructed in this paper. This paper further investigates the effect of three inlet tube structures on the temperature distribution and the concentration distribution of some species within the fuel cell.

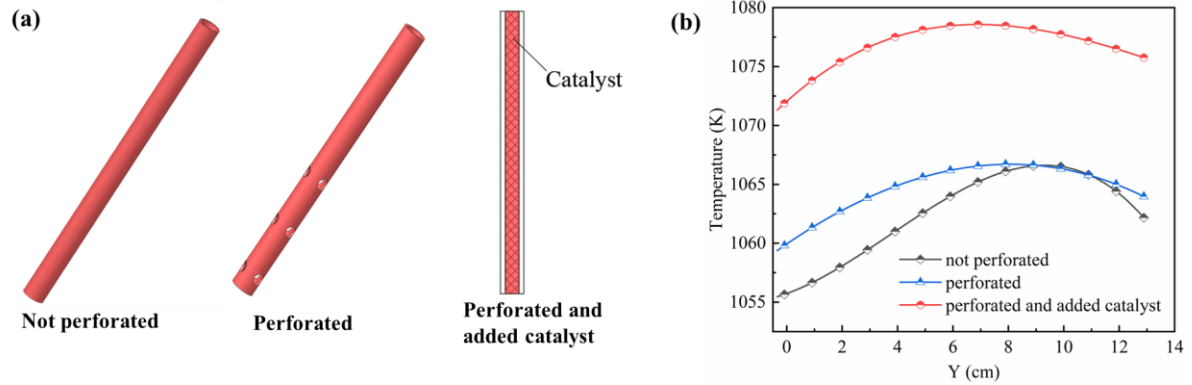


Fig. 5.(a) Ammonia gas inlet tube structure, and (b) Inlet tube outlet temperature distribution

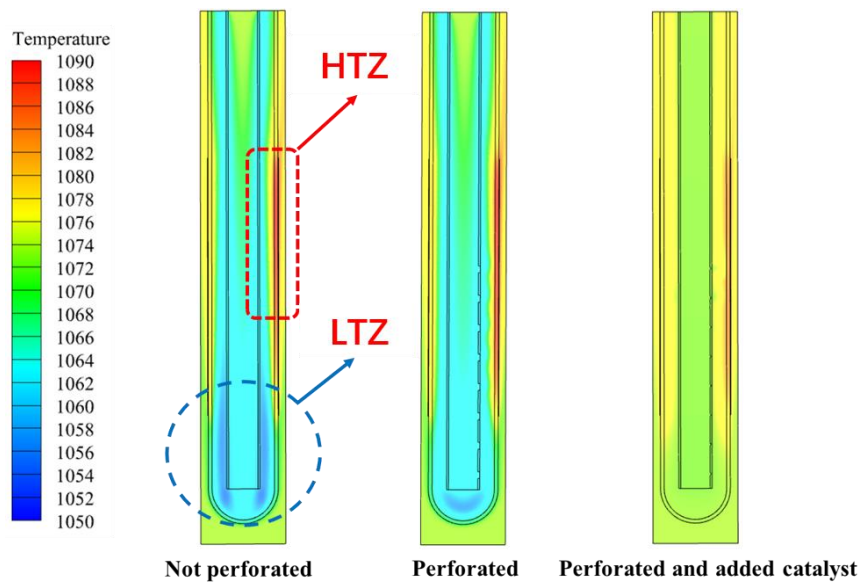


Fig. 6. Temperature distribution of the different tube structures

Fig. 5(b) shows the temperature distribution outside the tube of the three ammonia inlet tube structures discussed in this paper. It is easy to get that the temperature distribution outside the tube outlet of the three ammonia inlet tube structures are different. Both the perforation and the placement of ammonia decomposition catalyst inside the inlet tube can effectively improve the temperature distribution inside the fuel cell and make the temperature distribution of the fuel cell more uniform.

Under the operating conditions of an ammonia inlet temperature of 800 °C, an ammonia inlet tube length of 130 mm, and an ammonia inlet flow velocity of 0.5 m/s. Fig. 6 illustrates the temperature distribution of the cell interior for three different ammonia inlet tube structures. The temperature distribution of the cell interior for three different ammonia inlet tube structures are calculated as the temperature distribution of the cell middle section for the inlet tube structure not perforated, after perforated, and perforated with ammonia decomposition catalyst placed inside the tube, respectively. From the temperature distribution cloud diagram, it can be seen that the decomposition reaction of ammonia gas inside the cell absorbed heat form low-temperature zone (LTZ) and the H₂ oxidation release heat form a high-temperature zone (HTZ). The LTZ and HTZ inside the cell caused uneven temperature distribution, which affected the service life, operating stability and thermal shock resistance of DA-SOFC.

By comparing the temperature distribution clouds of the middle section of the fuel cell with three ammonia inlet tube structures, it can be found that the temperature variation between the LTZ and HTZ inside the fuel cell is 32 K with simple inlet tube adopted, which is much lower than the temperature difference of 100 K without the ammonia inlet tube [23], and the temperature variation within the electrode is around 22 K. After punching holes in the inlet tube, the temperature variation within the electrode becomes lower. It can be found that the LTZ inside the fuel cell is transferred from both sides of the inlet tube to the outlet of the inlet tube, and the low-temperature zone is reduced too, and the temperature difference between the LTZ and HTZ is only 30 K. The temperature difference inside the cell with the ammonia inlet pipe perforated is 15K, which is 7K lower than the temperature difference inside the cell with the ammonia inlet pipe unpunched. The reason is that the decomposition reaction of ammonia is not concentrated at the outlet of the inlet tube, but can be decomposed through the hole diffusion into the flow channel, and the scope of the LTZ inside the fuel cell is effectively reduced. To further optimize the temperature difference inside the cell, loading of ammonia decomposition catalyst is placed inside the perforated ammonia inlet tube to make the ammonia decompose inside the tube. From Fig.6, we can see that the temperature difference between the LTZ and HTZ inside the fuel cell is reduced to 13 K, and the temperature variation within the electrode decreased to approximately 1 K or even lower.

3.4. Influence of the number of holes in the inlet tube on the SOFC temperature

Since the perforation of the ammonia inlet tube affects the temperature distribution inside the direct ammonia fuel cell, this section mainly studied the effect of the perforations number of the ammonia inlet tube on the temperature distribution inside the cell. The working conditions of the cell are the ammonia inlet temperature of 800 °C, the ammonia inlet tube length of 130 mm, and the ammonia inlet flow velocity of 0.5 m/s. The electrochemical reaction area is considered to be in the section from 35 mm to 130 mm from the ammonia inlet, and the effect of the number of perforations of the ammonia inlet tube is from 70 mm to 130 mm.

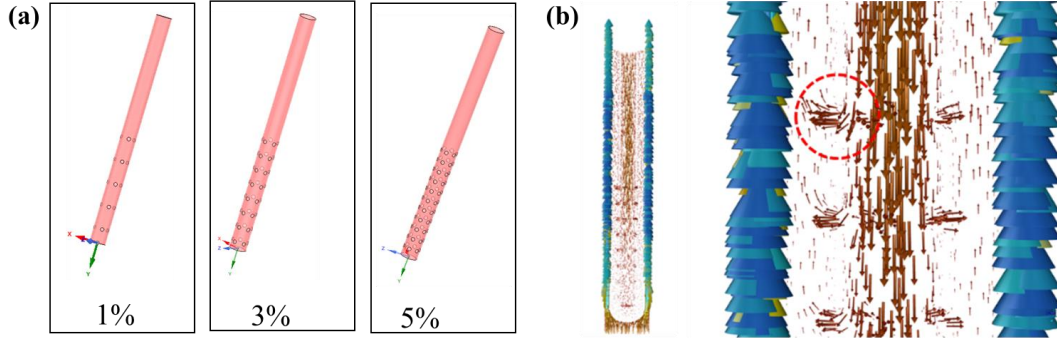


Fig. 7.(a) Ammonia gas inlet tube structure, and (b) Inlet tube outlet temperature distribution

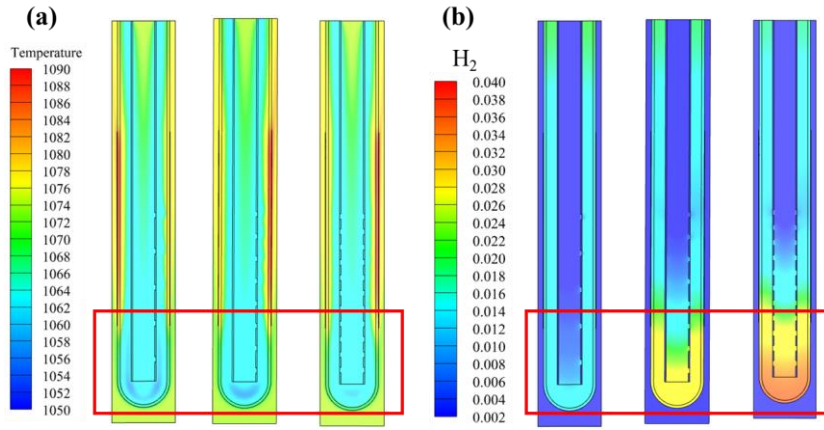


Fig. 8. (a)Temperature distribution in the middle section of the cell, and (b) Hydrogen concentration distribution in the middle section of the cell

Fig. 7(a) shows the structural diagrams of the ammonia inlet tube for 1%, 3%, and 5% perforated area, respectively. Fig. 8 shows the hydrogen concentration distribution as well as the temperature distribution of the intermediate cross section of the DA-SOFC corresponding to 1%, 3%, and 5% perforated area share, respectively. It can be seen that as the number of holes increases, the low-temperature region of the ammonia inlet tube outlet decreases. When the hole area is 1%, the highest concentration distribution area of hydrogen is at the outlet of the ammonia gas flow channel, and the utilization rate of ammonia is low. However, the highest concentration distribution area of hydrogen shifts from the outlet of the ammonia gas flow channel to the bottom of the fuel cell, and the concentration of hydrogen increases by 150% with the utilization rate of ammonia increased when the hole area is 3% and 5%. This is because the decomposition reaction occurs not only at the outlet of the ammonia inlet tube but also through the diffusion of holes (as in Fig. 7(b)) into the flow channel. As the number of holes in the inlet pipe increases, the ammonia gas diffused from the inlet pipe also becomes more, and the area where the ammonia decomposition reaction occurs is also wider. It can effectively avoid localized low temperature inside the battery caused by the concentrated decomposition of ammonia gas.

3.5.Effect of catalyst loading in the inlet tube on SOFC temperature

Fig. 9 simulates the effect of different catalyst loading in the ammonia inlet tube on the temperature distribution inside the DA-SOFC at ammonia inlet temperature of 800 °C, ammonia inlet tube length of 130 mm, and an ammonia inlet flow velocity of 0.5 m/s.

Fig. 9(a) reflects the temperature distribution inside the cell corresponding to 90%, 50%, and 20% of catalyst loading, corresponding to porosities of 0.1, 0.5, and 0.8, respectively. It can be seen that the content of the catalyst inside the ammonia inlet tube affects the temperature distribution inside the ammonia inlet tube, and the temperature inside the tube is higher when the porosity is smaller (the more catalyst loading). The decomposition reaction of ammonia is not intense and does not absorb too much heat. However, the decomposition reaction of ammonia occurs inside the tube is quicker when the porosity increasing (the less catalyst loading), leading to a lower temperature inside the ammonia inlet channel compared with the low porosity tube. It can be seen from Fig. 9(a) that the temperature difference between the two sides of the electrodes for different catalyst loading of DA-SOFC is maintained at about 1 K.

Fig. 9(b) reflects the effect of different catalyst loading on the change of hydrogen concentration inside the cell. The hydrogen concentration inside the cell of DA-SOFC with more catalyst loading (smaller porosity) is lower, which is due to the reduction of the flow channel of ammonia in the ammonia inlet tube due to more catalyst loading, and the reduction of the flow rate of ammonia, which in turn leads to the reduction of hydrogen concentration inside the cell. In summary, the hydrogen concentration inside the cell decreased as the catalyst loading in the tube increased from 20% to 90%, and the hydrogen concentration from ammonia decomposition decreased by about 57%.

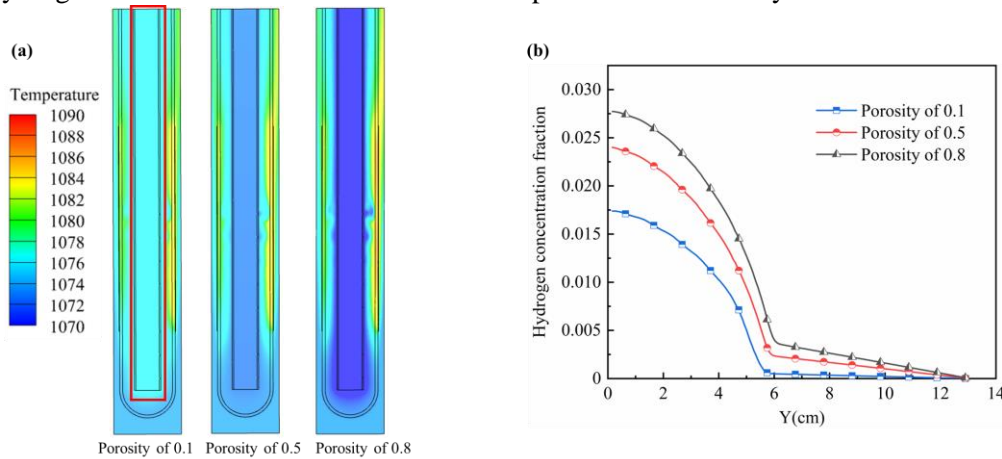


Fig. 9.(a) Temperature distribution, and (b)Hydrogen concentration distribution inside the cell with different catalyst loadings

3.6. Influence of the support materials on the temperature distribution of DA-SOFC

Some scholars [33-35] studied the influence of the support materials on the fuel cell performance, and the material of the support also effects the temperature distribution inside the fuel cell.

Table 3 Physical parameters of the support materials

Support material	Thermal conductivity W/(m·K)	Density kg/m ³	Specific heat capacity J/(kg·K)
1(Ni-YSZ)	6.23	4870	420
2(Stainless Steel)	16.27	8030	502.48
3(FeCr alloy)	294.05	7250	460

In this thesis, a numerical simulation model of DA-SOFC considering the support materials is developed to investigate the effect of the support materials on the temperature distribution inside the cell, and Table 3 shows some of the physical parameters of the three materials selected.

As shown in Fig. 10(a), it can be seen that when the thermal conductivity of the support material becomes larger, the electrochemical heat within the fuel cell is much easier to export and the temperature variation inside the cell is smaller. This is because the redox reaction of hydrogen and oxygen in the fuel cell releases heat, and the heat inside the cell be exported quickly and the temperature variation within the cell will be more even when using a support material with a higher thermal conductivity. The simulation results show that high thermal conductivity materials are beneficial to heat conduction and transfer inside the cell, which can make the temperature distribution inside the fuel cell more even and improve the thermal stability of DA-SOFC system.

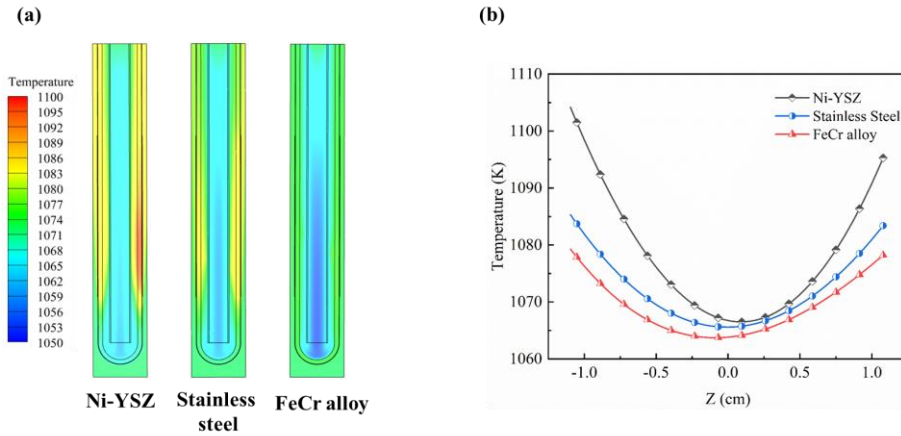


Fig. 10. Temperature distribution of (a) different support materials, and (b) cell cross section at 65mm from ammonia inlet

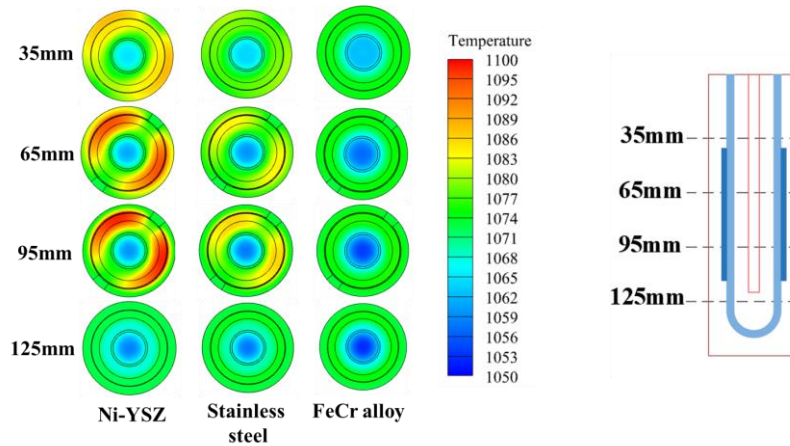


Fig. 11. Temperature distribution of at different cross-sectional positions

To analyse the temperature distribution of other cross-sections of the fuel cell, Fig. 11 shows the temperature distribution of the cross-section of the fuel cell taken 35 mm, 65 mm, 95 mm, and 125 mm away from the ammonia inlet, respectively. When the material with high thermal conductivity is used as the support of the fuel cell, it can be seen that the temperature distribution on both sides of the electrode of the cross-section of the fuel cell is more uniform(as in Fig.10(b)). This is mainly due to the fact that the heat generated in the fuel cell is better carried away.

4. Conclusion

(1) Increasing the ammonia inlet flow velocity and shortening the length of ammonia inlet tube can amplify the temperature disparity inside the cell. The ammonia inlet tube length is shortened from

130 mm to 90 mm, and the temperature difference inside the cell increases from 17 K to 45 K; inlet velocity of ammonia increases from 0.1 m/s to 1.1 m/s, and the temperature difference increases from 10 K to 20 K.

(2) Ammonia decomposition catalyst is placed inside the ammonia inlet tube to make the ammonia decompose inside the tube, which can reduce the temperature difference inside the DA-SOFC from 32 K to about 1 K.

3) The increase in the number of perforations in the inlet tube can reduce the low-temperature zone inside the cell, and the increase in the perforated area from 1% to 5% increases the maximum hydrogen concentration inside the cell by 150%; the increase in the catalyst loading inside the ammonia inlet tube reduces maximum concentration of hydrogen inside a cell, and the increase in the catalyst loading from 20% to 90% reduces the maximum hydrogen concentration by more than half.

4) By choosing a SOFC with a metal support, the whole temperature distribution of the fuel cell, especially on electrode sides, will be more uniform.

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Nomenclature

R_j	-	Product generation rate, [kg·m ⁻³ s ⁻¹]	ϕ	-	Electric potential
Y	-	Fuel cell longitudinal distance, [cm]	Subscripts		
N	-	Nernst potential, [V]	0	-	Exchange current density
i	-	the local current density, [A/m ²]	0,ref		Reference exchange current density
T	-	Temperature, [K]	Terminology		
F	-	Faraday constant, [C/mol]	DA-SOFC	-	Direct ammonia SOFC
Greek symbols			SOFC	-	Solid oxide fuel cell
τ	-	Curvature	HTZ	-	High-temperature zone
φ	-	Porosity	LTZ	-	Low-temperature zone
σ	-	Conductivity			

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