Carbon-based Solid Oxide Fuel Cells

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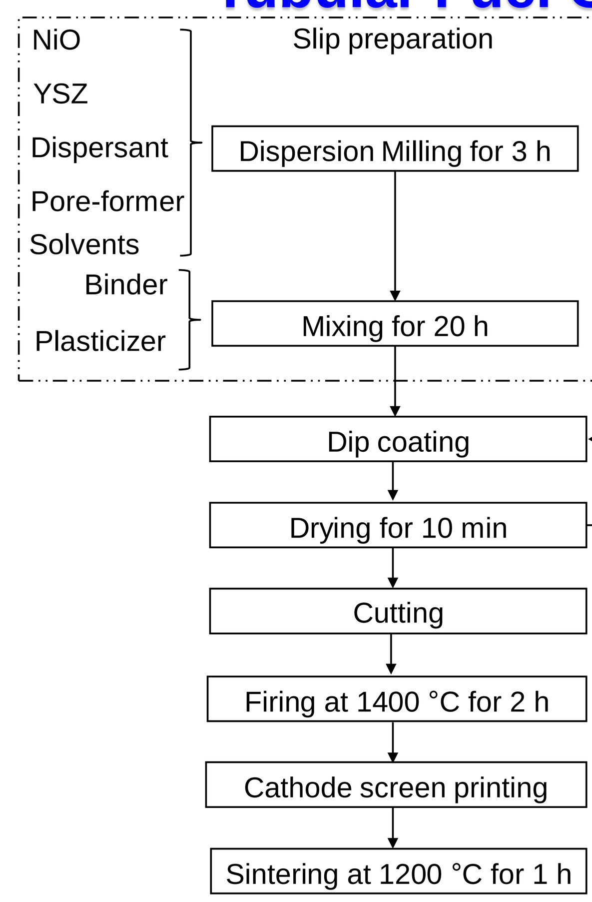
Objective

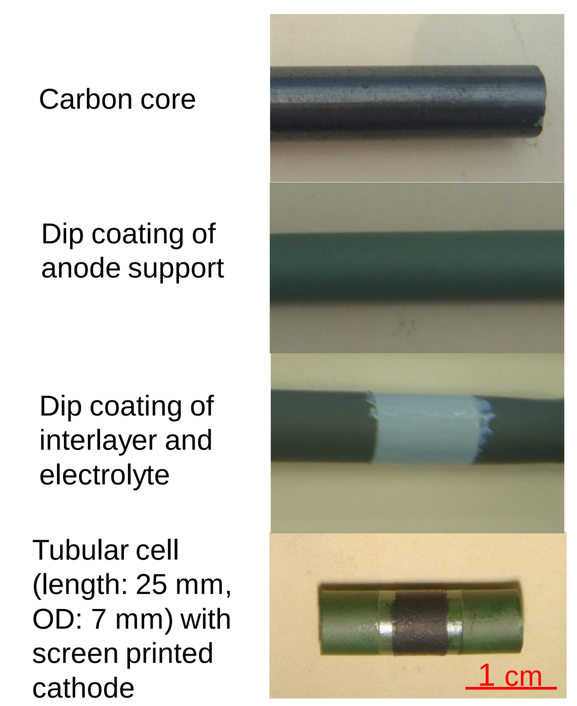
Demonstrate the technical and economic feasibility of building a kW scale pilot-plant coal-based fuel cell with participation by industries. This project will address initial development, scaling, and manufacturing of the core technology. Objectives for 2014 include the following:

- Design and fabricate a preliminary tubular fuel cell stack
- Demonstrate the operation of fuel cell stack with hydrocarbon and solid carbon fuels
- Study the effect of different types of carbonaceous fuels on the performance of the fuel cell
- Calculate the three phase boundary (TPB) length of the carbon fuel cell

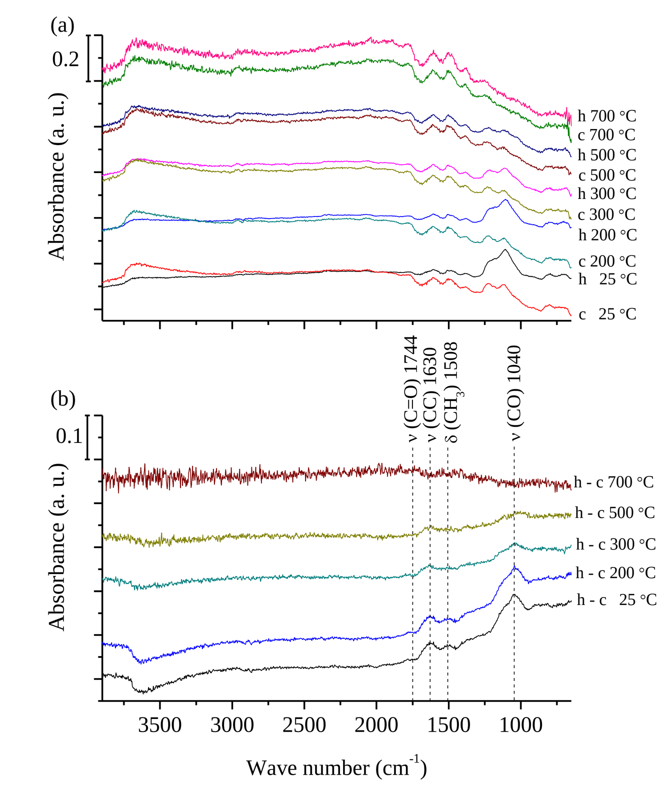
Tubular Fuel Cell Manufacturing



	Dips	Thickness (μm)	Solid loading (wt.%)
Anode support	35	800	42
Interlayer	3	25	40
Electrolyte	1	15	42

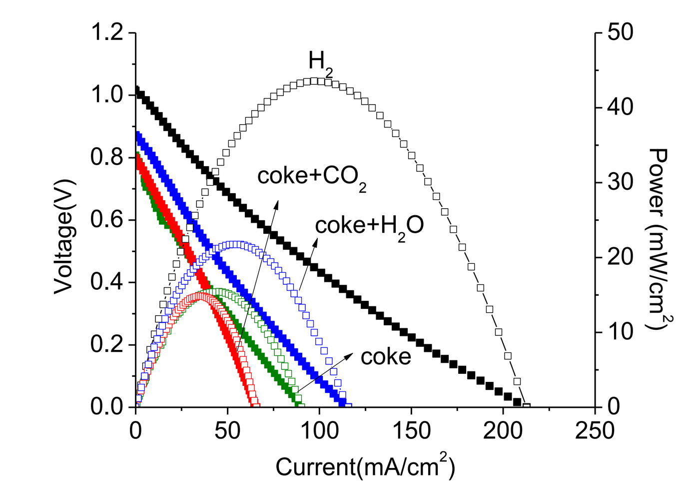


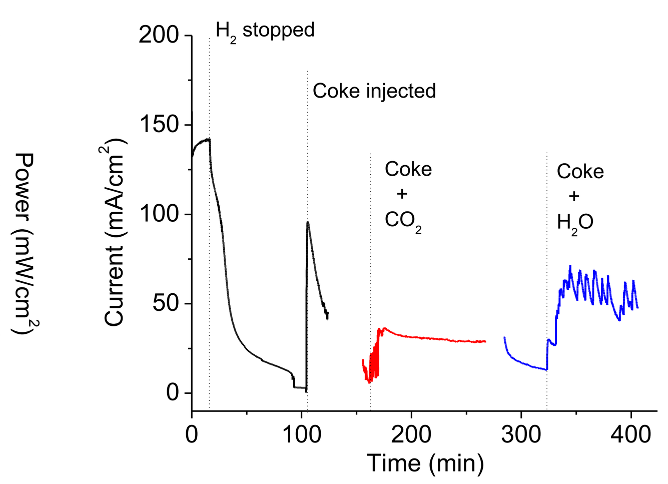
IR Study of Carbon Fuel Cell



- Upward peaks at 1040, 1508 and 1630 cm^{-1} indicate the depletion of C – O, CH_3 and C – C functional groups during heating process.
- A decrease in absorbance peaks intensity from 200 °C to 300 °C shows that coconut carbon surface reaction was started at this temperature range.

Effect of CO_2 and H_2O on Carbon Fuel Cell Performance





Coconut coke at 750°C
Load 300 mV

$$C+2O^{2-}\longrightarrow CO_2+4e^- \quad (1)$$

$$C+O^{2-}\longrightarrow CO+2e^- \quad (2)$$

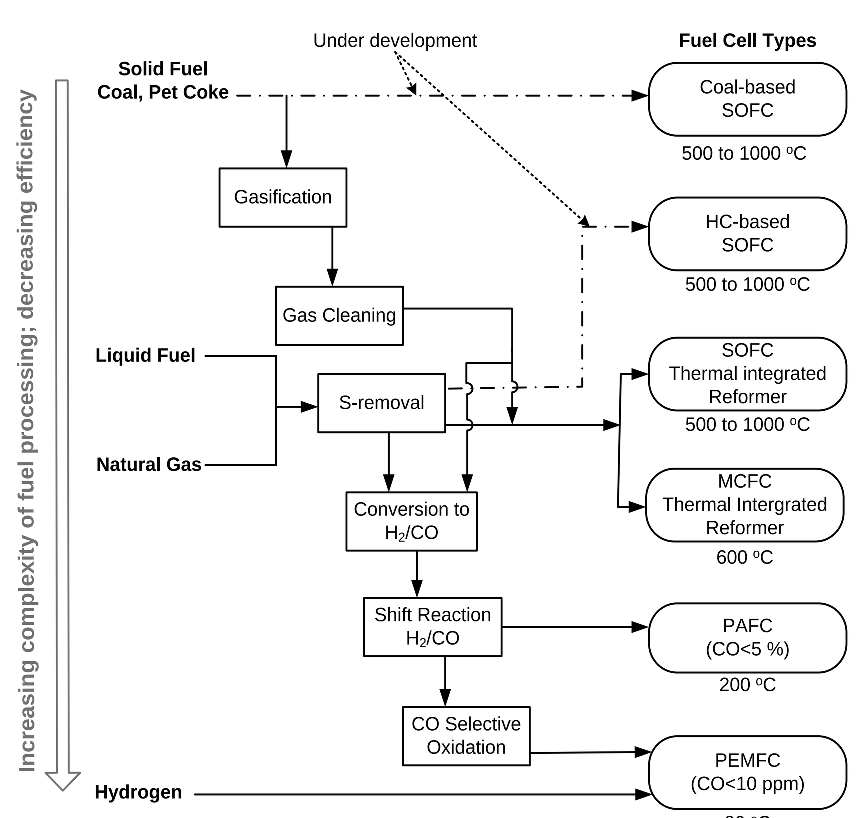
$$CO_2+C\longleftrightarrow 2CO \quad (3)$$

$$CO+O^{2-}\longrightarrow CO_2+2e^- \quad (4)$$

$$C+H_2O\longleftrightarrow CO+H_2 \quad (5)$$

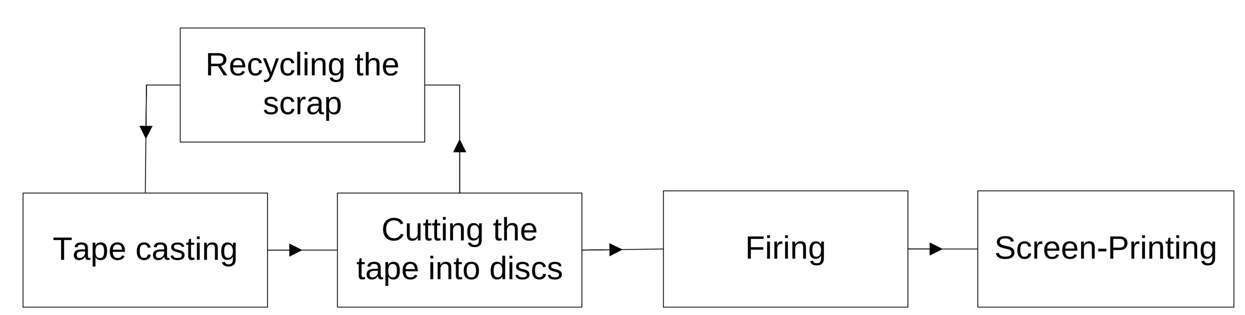
- Exposure to steam improved the fuel cell performance by promoting the formation of H_2, CO, CO_2

Fuel Processing and Fuel Cells



Ref: N.F. Brandon, S. Skinner, B.C.H. Steele, *Annu. Rev. Mater. Res.* **2003**. 33:183-213

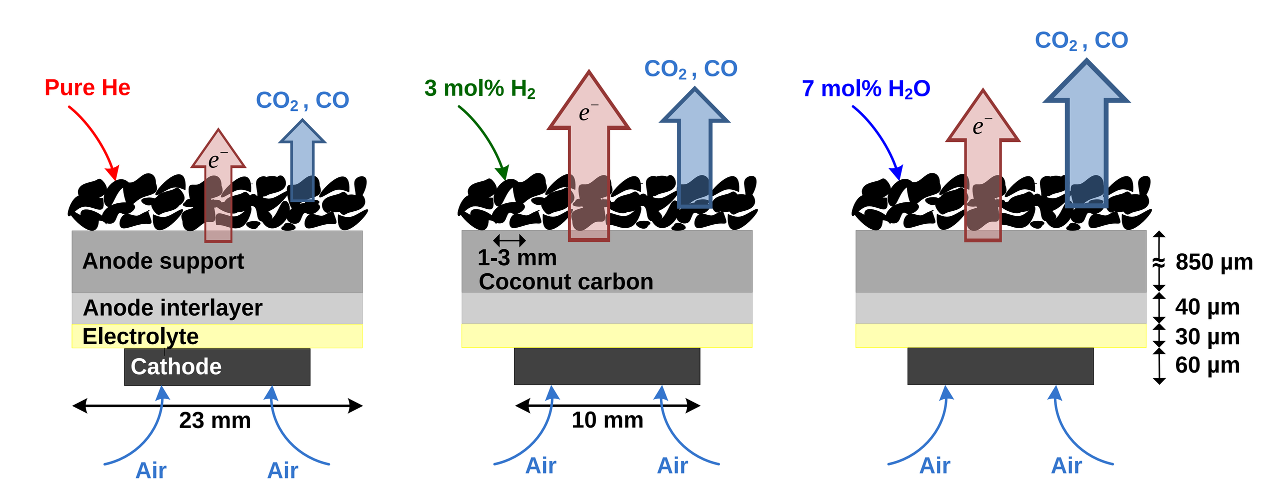
Cost Analysis of Fuel Cell



Components	Cost ($/kW)
Anode support	330
Anode interlayer	53
Electrolyte	112
Cathode interlayer	30
Cathode current collector	28
Total cost	554

- SOFC cost for generation of 1 kW electricity is about $ 555.

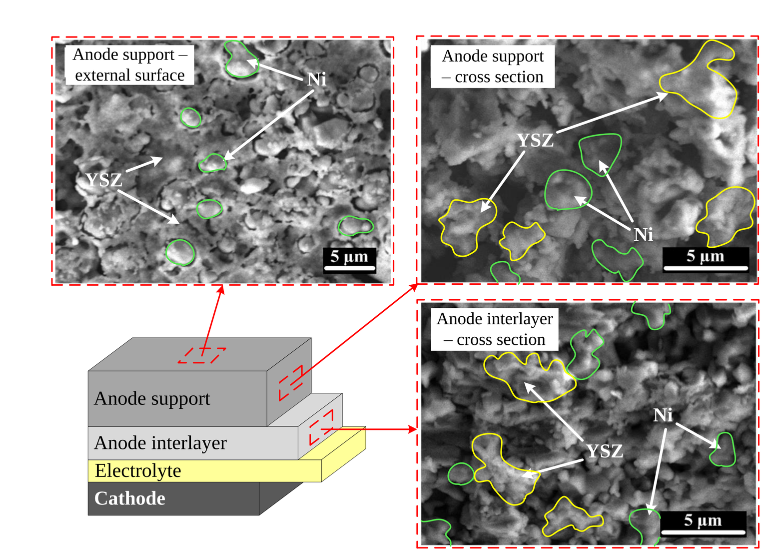
Direct Carbon Fuel Cell



- The addition of 3 mol% H_2 to the feed of carbon-SOFC enhances the electrochemical oxidation of carbon to CO and CO_2.
- The addition of 7 mol% H_2O increases the carbon-SOFC performance by utilizing H_2 and CO from the reaction of H_2O with carbon.

TPB Calculation for Carbon Fuel Cell

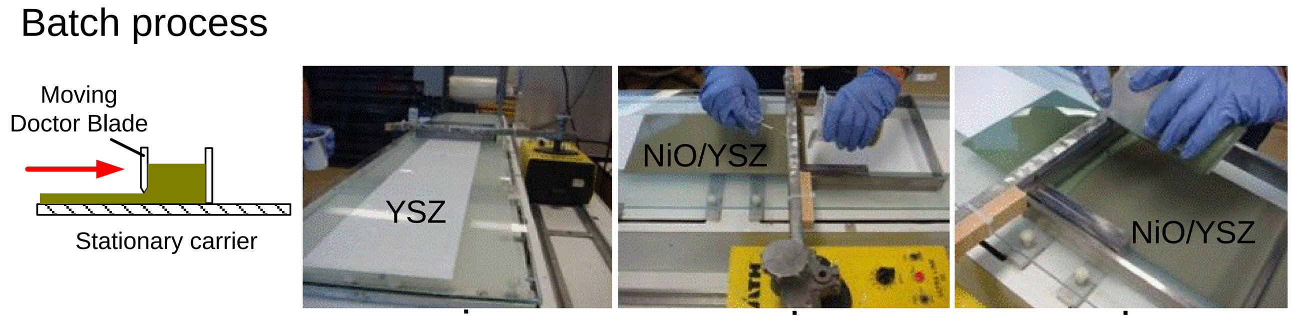
Fuel cell layers	Ni size (μm)	YSZ size (μm)	Porosity	TPB length (m/m^3)
Anode external surface	2.1	N/A	10%	6.96×10^{10}
Anode support	1.8	2.3	37%	8.51×10^{11}
Anode interlayer	1.2	1.5	17%	1.09×10^{12}



- The estimated TPB length at the anode interlayer is about 20 times greater than the TPB length on the anode external surface.
- The electrochemical oxidation of H_2 occurred at anode interlayer.
- The electrochemical oxidation of carbon occurred at anode external surface.

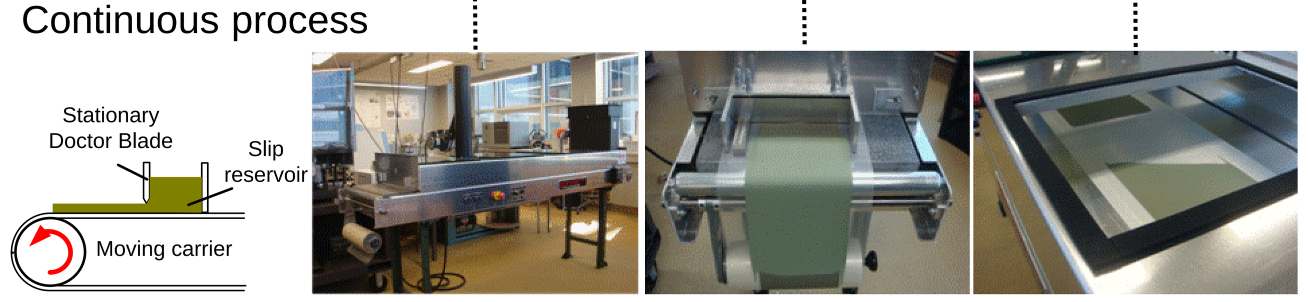
Fuel Cell Manufacturing

Tape casting
Batch process

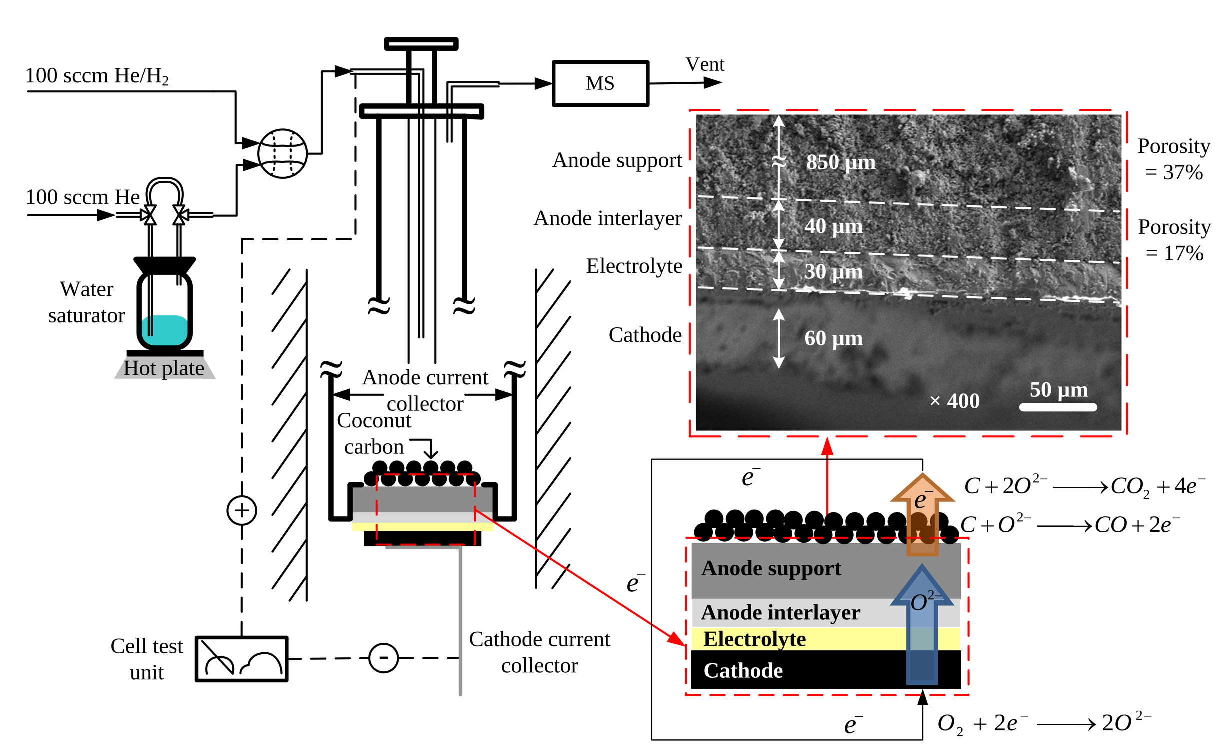


Electrolyte	Anode interlayer	Anode support
YSZ	NiO/YSZ 70:30 wt%	NiO/YSZ 65:35 wt%
Thickness:75 μm	Thickness:125 μm	Thickness:3000 μm

Tape casting
Continuous process



Carbon Fuel Cell: Operating Principle

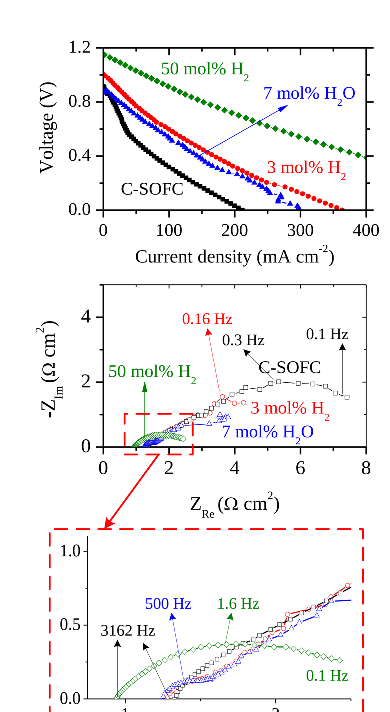


$$C+2O^{2-}\longrightarrow CO_2+4e^-$$

$$C+O^{2-}\longrightarrow CO+2e^-$$

$$O_2+2e^-\longrightarrow 2O^{2-}$$

Effect of H_2 and H_2O on Carbon Fuel Cell Performance



Feed stream condition	C-SOFC with Pure He OCV	C-SOFC with Pure He SCD	C-SOFC with Pure He diff.*	3 mol% H_2 OCV	3 mol% H_2 SCD	3 mol% H_2 diff.	7 mol% H_2O OCV	7 mol% H_2O SCD	7 mol% H_2O diff.
Exhaust gases	Molar concentration (mol%)								
H_2	0.049	0.051	0.002	2.837	2.743		2.068	2.105	0.037
CO	0.674	0.689	0.015	0.954	1.042	0.088	1.190	1.234	0.044
CO_2	0.0001	0.0007	0.0006	0.031	0.068	0.037	0.536	0.576	0.031
CH_4	0	0	0	0.00031	0.00035	0.00004	0.016	0.017	0.001

- The 7 mol% H_2O and 3 mol% H_2 feed improved the fuel cell performance comparing to the C-SOFC (pure He stream)
- The 3 mol% H_2 feed promoted oxidation of carbon to CO_2.
- The 7 mol% H_2O feed shifted the reaction on the anode from electrochemical oxidation of carbon to steam reforming of carbon to H_2 and CO.

Conclusions

- Tubular fuel cell reactor was successfully designed for continuous operation of SOFC.
- The addition of 3 mol% H_2 to the feed of carbon-SOFC enhanced the electrochemical oxidation of carbon to CO and CO_2.
- Carbon-SOFC performance increased by utilization of H_2 and CO from the reaction of carbon with H_2O.

Acknowledgement

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