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## Performance analysis of hollow fibre-based micro-tubular solid oxide fuel cell utilising methane fuel

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### ABSTRACT

Solid oxide fuel cell (SOFC) has been studied as one of the most amazing development in energy production that could work directly with hydrocarbon fuel without reforming procedure. This study was conducted to analyse the micro-tubular solid oxide fuel cell (MT-SOFC) in terms of its performance by utilising methane as the fuel, subsequently compared with hydrogen. MT-SOFC that was investigated in this work consisted of thin cathode layer, coated onto co-extruded anode/electrolyte dual-layer hollow fibre (HF); in which its anode was made of nickel (Ni), coupled with cerium-gadolinium oxide (CGO) as an electrolyte, whereas the cathode was lanthanum strontium cobalt ferrite (LSCF) and CGO. The physical analyses carried out were three-point bending test and scanning electron microscopy (SEM). X-ray diffraction (XRD) analysis was further conducted to examine the carbon deposition in HFs. In evaluating the performance of HFs, current-voltage (IV) measurement, as well as impedance analysis of various temperatures range from 500 °C to 700 °C were performed. Based on the results, the OCV, maximum power density and ohmic ASR of MT-SOFC exposed to methane fuel, were at 0.79 V, 0.22 W cm<sup>-2</sup> and 0.31 Ω cm<sup>2</sup>; compared to the other that was exposed to hydrogen fuel, recorded at 0.89 V, 0.67 W cm<sup>-2</sup> and 0.19 Ω cm<sup>2</sup> respectively. This indicates that there was a significant reduction in cell performance when methane was used as the fuel, due to the carbon deposition as proven by SEM, three-point bending and XRD.

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### Introduction

Solid oxide fuel cells (SOFCs) have been garnering attention as an excellent power-production innovation on the account of

high effectiveness in transforming chemical energy to electrical energy [1]. Oxygen ions in SOFCs system will diffuse over thin ceramic electrolyte film and respond with hydrogen to create electricity, resulting water as the only residual product.

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The common operating temperature of SOFC is between 800 °C and 1000 °C, generating noteworthy degradation and significantly restricting the selection of materials. Though such drawbacks have led to the improvement of intermediate temperature SOFCs (IT-SOFCs) in which works at lower temperature, within the 500 °C–700 °C range [2].

Up until now, there are two types of SOFC design, i.e. planar and tubular SOFCs, both have been broadly developed. In contrast to planar, the tubular is more reliable and can be operated without high temperature seals, demonstrating exceptional resistance to rapid thermal cycling [1]. In mid 1990s, Kendall started an advanced cell design, specifically called micro-tubular SOFCs (MT-SOFCs). This innovation was driven to enhance the performance of tubular SOFCs by decreasing the size of cell into micron scale. It is notable that numerous potential advantages do appear when the diameter of the cells is reduced [3]. MT-SOFCs offer more prominent resistance to thermal cycling, faster start-up capability, higher volumetric yield density and portable qualities, in contrast to both conventional planar and tubular SOFCs [4].

Moreover, MT-SOFCs can be fabricated using dry-jet wet extrusion method that produces hollow fibre support. For example, preparation of multi-layered hollow fibre (HF), i.e. dual-layer HF-based MT-SOFC, involves the single-step fabrication method such as dry-jet wet co-extrusion and co-sintering. In fact, it combines and simplifies the fabrication of anode/electrolyte dual-layer HF, greatly reducing production time and costs. In general, this single-step fabrication technique consists of three main stages: (i) development of particle suspensions by formulating anode and electrolyte spinning suspensions; (ii) arrangement of particle suspensions into a dual-layer HF precursor using dry-jet wet co-extrusion; and (iii) consolidation of dual-layer hollow fibre precursor via co-sintering process, which requires heating at high temperature. These stages play significant roles in the production of desired HF and should actually be implemented, starting from preliminary methods of ceramic membranes preparation [5].

Based on previous researches, material that is commonly used is yttria-stabilized zirconia (YSZ). As for recent studies however, cerium-gadolinium oxide (CGO) has taken over the equation instead. Despite so, with the advancement of CGO-based material for SOFC innovation, issues have arisen, thus drawing a boundary. One of them is the determination of fuel. In general, hydrogen is the most utilised fuel in fuel cells, typically formed from hydrocarbon reforming. On the off chance that the hydrocarbons can be utilised directly as a fuel, the whole expenses would be significantly decreased [6].

Moreover, hydrocarbon produce energy in a more efficient manner, given the presence of extra electrons in one molecule [7]. Hydrogen can only produce two electrons, whereas the methane is comprised of eight electrons in each molecule. This way, utilisation of hydrocarbon for SOFC frameworks is a splendid thought [8].

However, hydrocarbon based fuel can also cause carbon deposition; as a matter of fact, the presence of Ni catalyst in anode promotes this reaction when utilising hydrocarbon under specific conditions such as methane [9–11]. The carbon is deposited in electrodes, thus damaging the cell mechanically and reduces the performance of cell [12]. In this research,

an analysis on carbon deposition before and after performance test was conducted by using hydrogen and methane as the fuel source in order to investigate issues regarding carbon deposition. Furthermore, an investigation on the potential of methane in dual-layer hollow fibre based MT-SOFC has yet been done, clarifying the reason behind this study's main focus.

The objective of this work is, therefore, to evaluate the performance of dual-layer HF-MT-SOFC exposed to hydrogen and methane. The evaluations involved were open-circuit voltage (OCV), current-voltage (IV) measurement and impedance analysis with various temperature points, ranging from 500 °C to 700 °C. Three-point bending test and scanning electron microscopy (SEM) were likewise conducted to study the morphology and mechanical properties of HFs. On the other hand, carbon deposition evaluation was analysed by conducting X-ray diffraction (XRD) by using hydrogen and methane as fuels. In conclusion, this study aims to increase the understanding towards methane's flexibility as the fuel for CGO-based MT-SOFC.

## Methodology

### Materials

Commercially available 10 mol% of cerium–gadolinium oxide (CGO, with a specific surface area of 35 m<sup>2</sup> g<sup>-1</sup> d<sub>50</sub> 0.32 μm), nickel oxide (NiO, surface area of 5 m<sup>2</sup> g<sup>-1</sup> d<sub>50</sub> 0.55 μm) and lanthanum strontium cobalt ferrite, La<sub>0.6</sub>Sr<sub>0.4</sub>Co<sub>0.2</sub>Fe<sub>0.8</sub>O<sub>3</sub> (LSCF) were acquired from NexTech Materials Ltd. and utilised as provided. Dimethyl sulfoxide (DMSO) (Sigma–Aldrich), Polyethersulfone (PESf) (Radel A-300, Ameco Performance, USA) and polyethyleneglycol 30- dipolyhydroxystearate (Arlacel P135, Uniqema) were utilised as solvent, polymer binder and dispersant, respectively. De-ionized and tap water were utilised as interior and exterior coagulants.

### Fabrication of dual-layer HF

The method of producing dual-layer HFs in this research has been portrayed in detail elsewhere [1]. Throughout the preparation of anode/electrolyte HF of dual layers, two ceramic suspensions were prepared separately. The anode suspension was composed of 60 wt% of NiO and 40 wt% of CGO, while the electrolyte suspension contained CGO powder only. Table 1 shows the compositions of the spinning suspensions in producing dual-layer HFs. Ceramic powder was mixed with both DMSO and additive, then stirred for 48 h and PESf pellets were gradually added into the suspensions. The mixing was further carried out for an extra 48 h to obtain homogenous spinning suspension.

**Table 1 – Composition of the spinning suspension for dual-layer HFs.**

Layer	Composition (wt%)				
	NiO	CGO	PESf	Arlacel P135	DMSO
Anode	42.00	28.00	7.00	0.12	22.88
Electrolyte	–	60.00	6.00	0.12	33.88

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