ZURICH, MAY 19 – 23, 2025

2025 | 064

A holistic approach to solid oxide technology through optimization of its supporting components

Electrification and Fuel Cells Development

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ABSTRACT

Solid Oxide Technology – offers a lower carbon route to Net Zero. For SOFC (Solid Oxide Fuel Cell) and SOEC (Solid Oxide Electrolyser Cells), the core electrochemical activity takes place in the cell stack, with the required chemistry and engineering supported by the Balance of Plant (BoP). This BoP system of components can include fuel reforming, exhaust aftertreatment and removal of poisons. Optimisation of these components with the electrochemical stack, to function as a unit, offer benefits of greater reliability and durability combined with improved economic efficiency. In this paper we investigate how key aspects of system performance can be optimised through a greater appreciation of the role that advanced materials and catalysts play. As part of this we outline how some characterisation and analytical techniques grant insight into failure mechanisms that can help with next generation design. We look in detail at how catalyst components help extend fuel cell life via fuel and flue processing to remove/reduce unwanted gas components. These include non-methane hydrocarbons upstream of the fuel cell stack, the remnants of fuel components post stack and for removal of poisonous species such as chromium throughout the fuel cell system. This prevents significant coking (carbon build up) on active sites, ensure effective exhaust gas clean up and protects the fuel cell system from accelerated poisoning to achieve benefits in improved, durable performance.

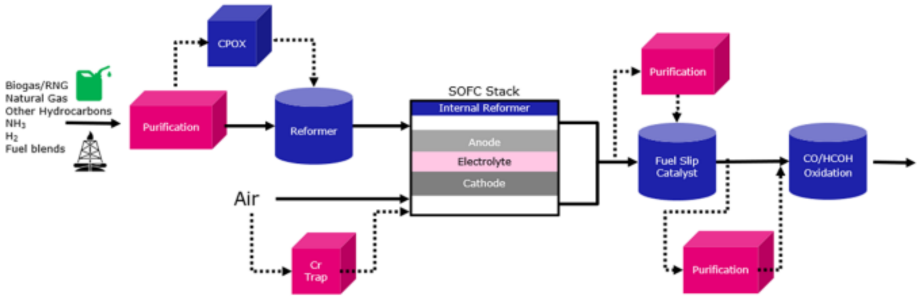

Figure 1. Simple schematic - gas processing BoP.

1 INTRODUCTION

Solid Oxide Fuel Cells (SOFCs) have long promised to deliver winning technology to the energy sector, offering high efficiency and low emissions by directly converting carbon-based fuels to electricity and heat. In recent years significant advances in their reversibility has furthered excitement, that reversible Solid Oxide Cell technology (rSOC) may emerge as an efficient means of storing renewable energy. Such technology could then support both distributed energy generation and storage with conversion of renewable energy into hydrogen (and other hydrogen-based fuels), thus helping balance supply and demand in energy systems [1]. A key characteristic of modern Solid Oxide Technology is its ability to integrate catalytic components which enhance their efficiency[2]. The integration of carbon capture with SOFC systems provides a potential pathway for carbon-neutral energy generation, enhancing both environmental and economic feasibility[3,4].

The concept of SOFC is based on high ionic conductivity of yttria-stabilised zirconia - at elevated temperatures (600-1000°C). At the cathode oxygen molecules are adsorbed and reduced to negative oxide ions. The chemical potential gradient passes these ions through the electrolyte to the anode fed by fuel. These oxidise the diffused fuel catalytically leading to the generation of electrons. With an external circuit the released electrons transfer to the cathode to complement the discharge process. A simple schematic of a typical SOFC and its working principles is shown in Figure 2

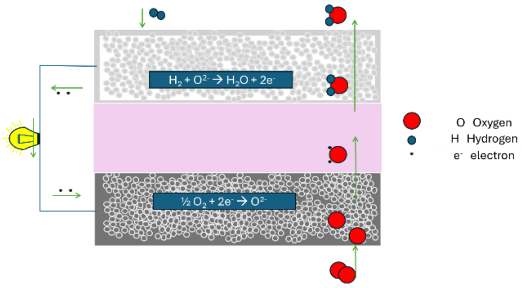

Figure 2. Basic SOFC electrochemistry with H_2.

To realise their potential, for wider adoption and mass market deployment it is expected that the economic challenge may be met through economies of scale, scope and taking advantage of the knowledge curve. However, before such advantages can be capitalised, other, critical barriers remain such as extending the fuel cell's durability. A commonly cited target for SOFC degradation is 0.2% per 1000 operating hours. This benchmark is deemed crucial for achieving long-term cost-effectiveness[5]. For stationary applications, a useful commercial lifetime of 80,000 to 90,000 hours is often cited, i.e. roughly 10 years of continuous operation. Bloom Energy reported a degradation rate of 2-3% per year after five years of operation indicating a potential lifespan significantly shorter than this target. Bloom have reported that their "hot standby" mode shows promise at slowing degradation[6]. Tests on rSOC systems have demonstrated varying lifespans. One study reported over 1,800 hours of fuel cell operation followed by more than 2,500 hours of electrolysis operation[7]. Another showed 2607 hours in fuel cell mode, 6043 hours in electrolysis mode, and 448 hours in hot standby, totalling over 9000 hours[8]. This suggests that reversible operation might influence lifespan, although the exact correlation requires further investigation. rSOC stack degradation is influenced by multiple factors including ageing (electrochemical & conventional), permanent and intermittent stresses such as thermal, current, mechanical wear, imperfect conditioning, poisoning & inhibition.

The electrochemical cell depends on a suite of supporting components—such as interconnects, seals, and current collectors, all essential for structural integrity, thermal management, and optimized reaction kinetics. However, a critical and sometimes underappreciated role is played by the catalyst components and purification units which are essential contributors to the overall performance and longevity of SOFC systems. The fact that degradation can affect fuel cell and BoP components differently and over different timescales illustrates the benefit of looking at the problem of durability from a holistic perspective through study of the performance of key components in the context of improving system performance over time.

2 FUEL AND FLUE GAS PROCESSING

Fuel processing (reforming), exhaust gas clean-up and poison removal are essential to SOFC performance. These fuel cell systems are designed to ensure that the fuel provided is compatible with the cell's operational requirements and free of contaminants that could impair performance. As it enters the fuel cell, undesirable components in a natural gas / bio gas fuel include siloxanes, chromium, sulphur and non-methane hydrocarbons. In the exhaust trace amounts of fuel and its breakdown components such as methane - CH_4, Hydrogen - H_2 Carbon Monoxide - CO and Formaldehyde - CH_2O must be removed by oxidation. This not only safeguards the catalytic components but also enhances the cell's overall efficiency and longevity by preventing degradation and ensuring a stable operating environment.

2.1 Silicon / Siloxanes

Silicon-based contaminants are known to severely affect the performance of SOFC anodes, even at parts-per-billion levels, where failure has been attributed to the gas diffusion blockage by dense silicon dioxide layer formation where contamination/degradation is more rapid when the anode is polarized.

2.2 Chromium

Chromium, released from steel components can significantly impact the performance of solid oxide fuel cells[9] (SOFCs) in several ways[10]. Chromium can migrate to the cathode and degrade electrochemical performance. It can react with the electrode materials, forming chromium oxide or other compounds that block active sites, increasing the polarization resistance and reducing the effectiveness and efficiency of the cathode. Chromium can also affect the long-term stability and compatibility of materials within the SOFC. This can lead to structural degradation and reduced mechanical integrity of the cell components. To mitigate these issues, researchers and engineers are exploring various strategies, such as developing protective coatings for steel components, using alternative materials for interconnects, designing cathodes that are less susceptible to chromium poisoning and the development of technology to trap chromium species upstream of the fuel cell stack.

2.3 Sulphur

Sulphur poisoning is a major challenge for SOFC. Sulphur species, generally, from odorants in the natural gas or from natural sources in biogas, interact with the nickel-based electrodes leading to reduced cell performance. Nickel is highly susceptible to sulphur poisoning. Sulphur compounds chemisorb onto the nickel surface, blocking active sites essential for the electrochemical reactions. This leads to a reduction in anodic activity, increasing polarization resistance, and subsequently reducing the overall cell efficiency. Cathode materials, such as lanthanum strontium cobalt ferrite (LSCF), can also be affected through formation of sulphates on the cathode surface, which hinder the oxygen reduction reaction, important for maintaining the cell's performance. Continuous exposure to sulphur compounds can lead to irreversible changes in the anode and cathode microstructures, significantly shortening the lifespan of the cells.

2.4 Non-methane hydrocarbons

Higher hydrocarbons[11] (ethane, propane etc.) in natural gas can partially oxidise or crack to form carbon, which poses a challenge for solid oxide fuel cells (SOFCs) as it can lead to carbon deposition, affecting performance. A catalytic pre-reformer can convert these higher hydrocarbons to syngas, (CO & H_2) mitigating this issue.

2.5 Flue Gas Clean up

In addition to controlling poisoning and inhibition of critical fuel cell activities, fuel cell components also play a critical role in process gas clean up removing trace fuel and related components that escape the electrochemical process and need to be oxidised via a combustion catalyst before release to the atmosphere.

3 CHARACTERISING DE-ACTIVATION

To better understand how to reduce the impact of poisoning and inhibition, characterisation tools have been developed to decipher failure mechanisms. Through comparison of samples that have been aged e.g. through either real-world fuel cell operation or via a process designed to simulate aging, one can gain insight into how materials lose their ability to function over time. Some of the techniques available to study how materials age are summarised in Table 1

Technique	Methodology	Insights / Info
X-ray photoelectron spectroscopy[12] XPS	Irradiated with X-rays, electrons are excited & ejected - information on binding energy	Elemental composition, chemical state, and electronic structure of the material
X-ray diffraction[13] XRD	X-rays interact with crystal lattice to produce a diffraction pattern given by Bragg's law	Identify the material's crystalline phases and structural properties
Scanning Electron Microscopy[14]	Electrons beam – back scattered / 2nd electrons are detected	Provides info on surface morphology & material composition
Electron Probe Microanalysis[15]	High-energy electrons excite atoms to emit x-rays (identifiable)	Precise elemental composition with high spatial resolution
Transmission Electron Microscopy[16]	Electron beam (thin sample) – transmitted electrons magnified projected – image	Internal structure of materials at the atomic scale including defects.
Inductively Coupled Plasma	High- Temp plasma (-10,000 K – ionizes material elements - Identified by mass spectroscopy.	Elemental composition of samples with high sensitivity and precision
Thermo - gravimetric Analysis[17]	Sample in high-precision balance & heated at defined rate - mass loss is recorded.	Heat stability, decomp. temp, oxidation states & composition

Table 1 – Characterisation Methods.

4 PRE-REFORMING CATALYSTS

Samples of pre-reforming catalysts were returned from the field – as part of a "real world" durability study in a SOFC system after 8000 hours of operation. Samples PR1 – PR5 were arranged in order from the inlet of the reactor to its outlet. Their ability to function as reforming catalysts was evaluated in a test rig using ethane, CH_2-CH_2 gas as the fuel. The catalyst samples were tested over a temperature range 425 – 775 °C to determine how much of the fuel from an ethane / steam mix was converted (to syn gas). The test results are compared to those from a fresh sample (standard) de-greened, through aging for 250 hours.

The catalytic performance of all the samples has dropped especially in the 450 – 675°C temperature range. At 650°C most samples operate at 75-80% of the standard sample. One sample (taken close to the inlet) has a much lower performance at this temperature, operating at 25% efficiency.

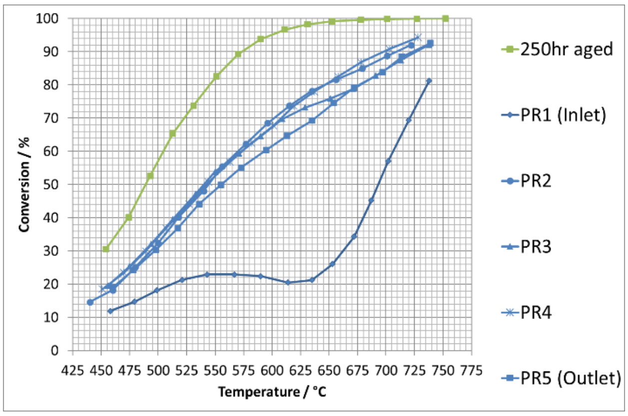

Figure 3. Comparing aged reformer catalysts, Steam : Carbon ratio of 3 (S:C=3)

Various characterisation techniques were utilised to gain further insight into the impaired performance – to test an hypothesis that this was due to a thermal event or carbon deposition.

X-Ray diffraction[18], XRD of the powdered catalyst showed no significant increase in crystallinity or in phase changes within the catalyst support – indicating that sample was not exposed to a prolonged elevated temperature. Scanning Electron Microscopy SEM reveals that the morphology is similar to the standard confirming the finding of the XRD data that long term exposure to excessive heat is unlikely. Silicon contamination is evident.

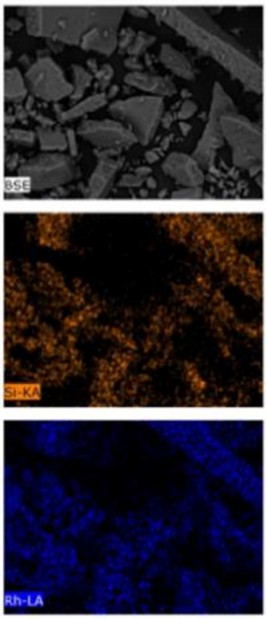

Figure 4. SEM of an aged reformer catalyst

Electron Probe Microanalysis (EPMA), also known as Electron Probe X-ray Microanalysis, provides quantitative elemental analysis. While not a direct structural analysis technique like XRD or Transmission Electron Microscopy (TEM), EPMA contributes valuable information that can be crucial for understanding material structure, particularly when combined with other analytical methods. EPMA did not show significant contamination e.g. through sulphur poisoning.

Inductively Coupled Plasma[19] (ICP) was used to conduct an elemental and isotopic analysis of the recovered powder catalyst. This showed substantive Silicon presence – confirming the finding by SEM. TGA showed there was no significant weight losses compared to the fresh sample, but some additional CO_2 was observed coming off the poorly performing sample. This supports the hypothesis that coking or carbon deposition was contributing to the lower performance.

5 AGING COMBUSTION CATALYSTS

Two combustion catalyst formulations CC1 and CC2 (both based on platinum group metals, pgm catalyst dispersed on alumina) have been exposed to progressively more severe ageing conditions. The catalysts were evaluated for CO uptake, BET surface area and any metal loss after ageing. Selected formulations were tested for methane combustion, start-up and steady state combustion activity.

5.1 Experimental

Catalysts were aged in a 30% steam, 70% air mixture at a total flow rate of 300ml/min. Ageing was carried out in a tube furnace as shown in Figure 5. Ageing, characterisation and testing was carried out as shown in Table 2.

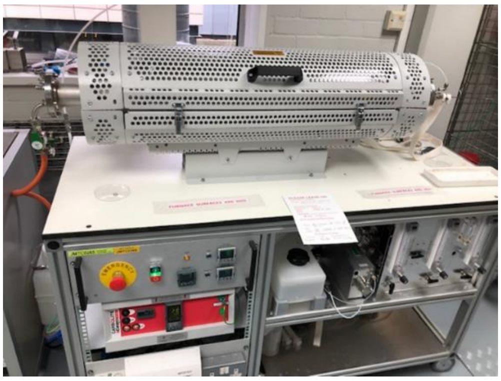

Figure 5. Tube furnace used for catalyst ageing

Catalyst	Ageing Tempe / °C	Ageing Time /h	Characterisation	Activity testing
CC1	1000	25	Yes	Yes
CC1	900	200	Yes	Yes
CC1	850	200	Yes	Yes
CC1	800	200	Yes	Yes
CC1	750	200	Yes	Yes
CC1	750	50	Yes	No
CC1	750	50	Yes	No
CC1	750	1	Yes	No
CC1	625	200	Yes	No
CC1	500	200	Yes	No
CC1	500	50	Yes	No
CC1	500	5	Yes	No
CC1	500	1	Yes	No
CC2	1000	25	Yes	Yes
CC2	900	200	Yes	Yes
CC2	850	200	Yes	Yes
CC2	800	200	Yes	Yes
CC2	750	200	Yes	Yes
CC2	750	50	Yes	No
CC2	750	50	Yes	No
CC2	750	1	Yes	No
CC2	625	200	Yes	No
CC2	500	200	Yes	No
CC2	500	50	Yes	No
CC2	500	5	Yes	No
CC2	500	1	Yes	No

Table 2 - Summary of catalyst ageing tests

Catalyst testing was carried out with single channel fixed bed micro reactors. Three rigs were used, one for methane combustion, a second for start-up testing and a third for steady state testing. The test rigs are all built to the same design specification which is illustrated schematically in Figure 6 with a photograph of a rig in Figure 7.

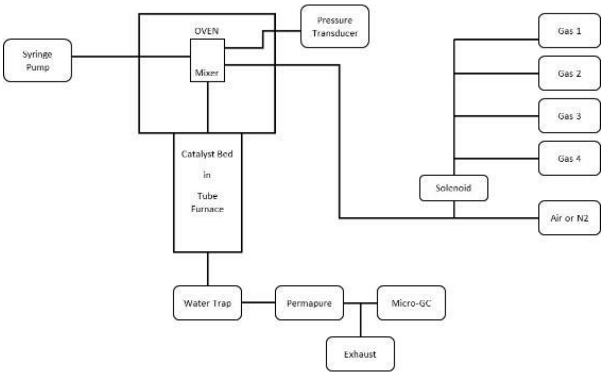

Figure 6. Schematic of single channel test rig

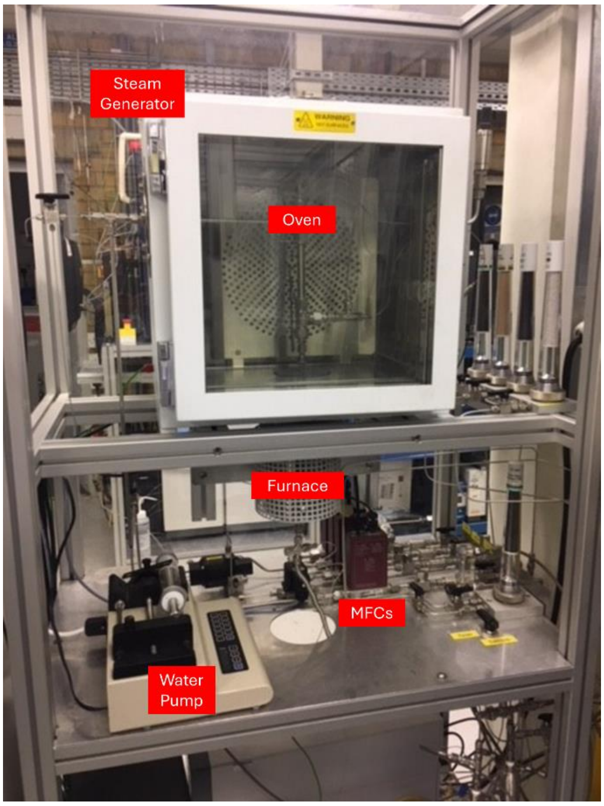

Figure 7. Photograph of single channel test rig

These rigs were designed to carry out a wide range of experiments including hydrocarbon reforming, water gas shift, combustion and selective oxidation and so each has a number of gas channels available. Each gas channel consists of a mass flow controller as well as associated on-off valves, filters and non-return valves. Liquid feed is injected from a syringe pump into a mixing chamber held in a heated oven at 175°C and mixed with the dry gas. The inlet feed then passes through the catalyst bed contained in a 6 mm outside diameter, 4mm internal diameter quartz reactor tube inside a 25 mm internal diameter tube furnace. The catalyst bed comprises 0.015 g of catalyst in 250-355µm grit form mixed with an inert diluent (cordierite, 0.085g, 250-355µm grit), giving a catalyst/diluent bed approximately 5 mm long, held in position between two quartz wool plugs. A 1/16" diameter type K thermocouple was used to hold the bed in position from the bottom of the tube and was used as an over temperature alarm. A second 0.5 mm diameter type K thermocouple was used for initial setup and goes through the lower quartz wool plug and sits at the outlet of the catalyst bed. This catalyst bed temperature and the furnace temperature are logged during testing. After the catalyst bed, the product gas enters a knock-out trap which removes bulk liquid which includes ethanol, water and other condensable reaction products. An additional Permapure (Nafion based) dryer removes residual water and ethanol. The product gas is analysed using a micro GC analyser. A molecular sieve 5A° column is used to measure hydrogen, nitrogen, methane and carbon monoxide using argon as carrier gas. Even though both carrier and sample gases are dried, the molecular sieve channel was still contaminated by trace amounts water over time meaning that the efficiency of separation is affected, limiting the maximum continuous period of operation to around 16 hours. A regeneration step (heating the column to 180°C for 8-10 hours) was then required. A second channel with a Poraplot U column was used to measure carbon dioxide, methane, ethene and ethane with helium as carrier gas. The GC was calibrated using a reference mixture of known concentration of each component that was certified by the gas supplier.

For methane combustion, conversion is defined as;

$$Conversion\ (\%) = 100\ X\ \frac{\%\ CO + \%\ CO2}{\%\ CO + \%\ CO2 + \%CH4} \qquad (1)$$

For ethanol combustion, since unconverted ethanol is removed before gas analysis, conversion cannot be determined using these components. Instead, conversion is calculated using the nitrogen as an internal standard;

$$Conversion\ (\%) = 100\ X\ \frac{\frac{C1}{N2}(outlet)}{\frac{C1}{N2}(inlet)} \qquad (2)$$

Where C1 $(outlet) = \%CH4 + \%CO2 + \%CO + 2\ x\ (\%C2H4 + \%C2H6)\quad by\ GC$

$$N2\ (outlet) = \%N2\ by\ GC$$

$$C1\ (inlet) = 2\ X\ moles\ ethanol\ per\ minute$$

$$N2\ (inlet) = moles\ N2\ per\ minute$$

For methane combustion testing, the gas inlet composition was 1% methane, 2% steam in air, with a total flow rate of 206 ml/min and 0.015g catalyst diluted with 0.085g cordierite. Activity was recorded between 400°C and 700°C ramping at 2°C/min.

For start up testing, the gas inlet composition was 2.46% ethanol, 9.82% water in air, with a total flow rate of 228 ml/min and 0.015g catalyst diluted with 0.085g cordierite. The catalyst was ramped from 100°C at 2°C/min.

For steady state testing, the gas inlet composition was 1.918% hydrogen, 0.002% methane, 0.244% carbon monoxide, 2.737% carbon dioxide, 8.505% steam and 86.594% air with a total flow rate of 100 ml/min and 0.015g catalyst diluted with 0.085g cordierite. Testing was carried out at a fixed gas inlet temperature of 610°C.

Since the test rigs do not have a gas inlet temperature thermocouple, blank experiments were carried out on each rig using only cordierite as sample. The catalyst bed thermocouple was used to record the temperature without any reaction occurring at a given furnace temperature which was then used as the gas inlet temperature during testing with catalysts.

CO chemisorption was carried out using a Micromeritics AutoChem II analyser. The catalyst surface was first cleaned under reducing conditions at temperature to ensure the active metals are in a metallic rather than oxide form and so capable of chemisorbing carbon monoxide. Carbon monoxide is then pulsed into an inert gas stream with a calibrated gas loop and passed over the catalyst. Carbon monoxide uptake is measured using a thermal conductivity detector. The output of the analysis is a measurement of carbon monoxide uptake per gram of catalyst which, using the metal content of the sample can be used to calculate the percentage dispersion of the metal particles.

The catalysts were analysed by nitrogen physisorption. Samples were degassed at 200°C under vacuum before measurement. The BET model was used for the surface area calculation using the IUPAC recommended Rouquerol method.

Metal content was determined by dissolving the catalyst samples using proprietary digestion techniques and carrying out analysis by inductively coupled plasma – optical emission spectroscopy.

5.2 Results

Catalyst characterisation data is shown in Table 3.

Catalyst	Ageing Temp / °C	Ageing Time/h	Relative Surface Area	CO uptake / cm3/g
CC1	500	1	1.00	1.8
CC1	500	5	0.97	1.5
CC1	500	50	0.95	1.4
CC1	500	200	0.92	1.31
CC1	625	200	0.85	0.94
CC1	750	1	0.93	1.07
CC1	750	5	0.90	0.71
CC1	750	50	0.85	0.43
CC1	750	200	0.80	0.42
CC1	800	200	0.76	0.34
CC1	850	200	0.67	0.19
CC1	900	200	0.63	0.17
CC1	1000	25	0.66	0.15
CC2	500	1	1.00	2.09
CC2	500	5	0.99	2.04
CC2	500	50	0.97	1.81
CC2	500	200	0.95	1.45
CC2	625	200	0.85	0.18
CC2	750	1	0.93	0.3
CC2	750	5	0.89	0.2
CC2	750	50	0.88	0.07
CC2	750	200	0.86	0.06
CC2	800	200	0.87	0.04
CC2	850	200	0.84	0.03
CC2	900	200	0.77	0.02
CC2	1000	25	0.70	0.01

Table 3 - Catalyst characterisation data

Relative surface area decreases with increasing temperature, particularly for temperatures above 750-800°C (Figure. 8) over 200 hours ageing.

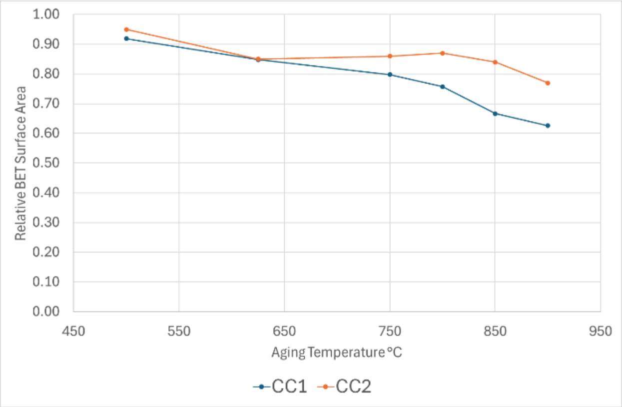

Figure 8. BET surface area – 200 hour ageing

This can be attributed to metal loss through high temperature volatilisation and is particularly noticeable when ageing above 750°C. The loss is more significant for CC2 than for CC1 (Figure 1). The specific properties including the design of the alloy mix in the constituent platinum group metals pgm accounts for the greater stability of catalyst CC1. This insight also allows fuel cell integrators to appreciate realistic boundary conditions for catalyst performance so that the maximum continuous operating temperature for CC2 would therefore be 750°C although the catalyst will tolerate brief exotherms to higher temperatures. Sustained exposure to higher temperatures will lead to lower durability.

This is further evidenced in a BET study. At 500°C, BET surface areas decrease slowly over time, whereas at 750°C there is a greater decrease (**Error! Reference source not found.**). If a fuel cell's operation regularly rise to temperatures above 750°C, the more robust catalyst, CC1 should grant greater stability and confer longer durability.

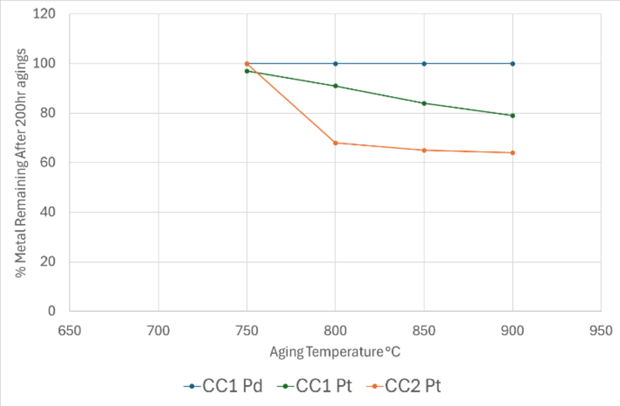

Figure 1 : Catalyst metal – 200 hour ageing

5.3 Catalyst Activity

Methane combustion activity is shown in Figure 10. All CC1 catalysts show significantly higher activity than the CC2 catalysts. For CC2, there is a significant drop-in activity from the sample aged at 750°C to the sample aged at 800°C, with higher temperature ageing having much less effect. This indicates that so called de-greening of CC1 occurs at 800°C but then after that the catalyst is not significantly affected further by the additional temperatures of 900/1000°C. This improved performance should lead to greater durability.

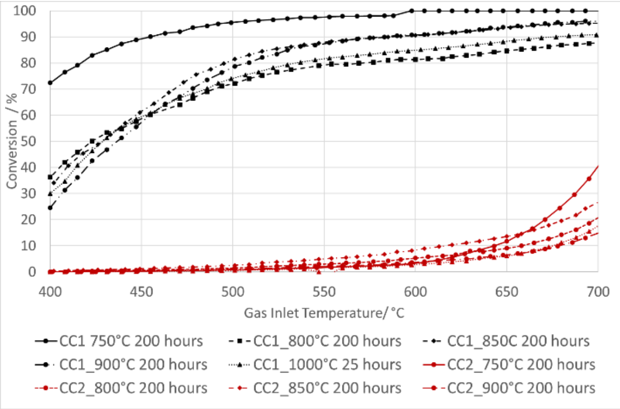

Figure 10. Catalytic Combustion – Methane

Steady state performance is shown in Table 4. For these experiments the gas inlet composition was 1.918% hydrogen, 0.002% methane, 0.244% carbon monoxide, 2.737% carbon dioxide, 8.505% steam and 86.594% air with a total flow rate of 100 ml/min and 0.015g catalyst diluted with 0.085g cordierite. Testing was carried out at a fixed gas inlet temperature of 610°C

All catalysts combust hydrogen and carbon monoxide with no detectable hydrogen or carbon monoxide in the outlet gas stream. All CC1 catalysts fully combust methane, however the lower detection limit is 5 ppm on the analyser used. Methane slip is seen for all CC2 catalysts.

Catalyst	Ageing Temp °C	Ageing time/h	H_2 %	CO %	CH_4 ppm
CC1	750	200	0.00	0.00	0
CC1	800	200	0.00	0.00	0
CC1	850	200	0.00	0.00	0
CC1	900	200	0.00	0.00	0
CC1	1000	25	0.00	0.00	0
CC2	750	200	0.00	0.00	9
CC2	800	200	0.00	0.00	17
CC2	850	200	0.00	0.00	12
CC2	900	200	0.00	0.00	13
CC2	1000	25	0.00	0.00	19

Table 4: Steady state catalyst activity

A more active hydrocarbon can be used to probe catalyst performance in more benign conditions.

Ethanol combustion under start up conditions is shown in Figure , and a significant effect of ageing temperature on catalyst performance is observed. Light off temperature increases with ageing temperature. For CC2 aged at 850°C or above, the light of temperature is higher than that of CC1 aged at the same temperature.

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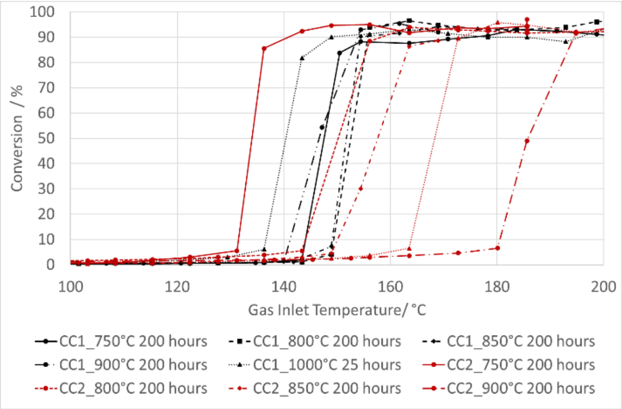

Figure 11. Start-up testing – conversion

CC1 catalysts show better performance for combustion than CC2 formulations and have lower metal losses. Under milder ageing conditions, CC2 has a lower light off temperature than CC1, however with increasing temperature CC2 shows higher light off temperatures. Understanding system requirements for the peak temperatures and expected duration of exposure should help in designing more durable fuel cell performance. The maximum recommended continuous operating temperature for CC2 is 750°C and 900°C for CC1.

6 CHROMIUM POISONING

The deleterious impact of chromium species[20] on SOFC performance is widely acknowledged[21]. Their primary source is the metallic components upstream and integral to the fuel cell, where ferritic stainless steel alloys which contain chromium are chosen for corrosion resistance at high operating temperatures. At these high temperatures of (500-1000°C), chromium forms volatile species, primarily chromium trioxide (CrO_3) and chromium oxyhydroxide ($CrO_2(OH)_2$), in the presence of oxygen and water vapor. These volatile chromium species are transported by the airflow towards the cathode side where they react with the cathode material, typically a mixed ionic-electronic conducting (MIEC) oxide, and deposit as chromium oxides (Cr_2O_3) or other chromium-containing compounds.

To prevent the chromium depositing on the fuel cell's active components they must be protected by traps or "getter" technology[22]. These active materials may be seen as sacrificial components with a purpose to trap the chromium species before they migrate to active fuel cell components and inflict significant damage. These getters are incorporated into fuel cell design in the interconnect or as a separate component upstream of the stack. Getters need to be very effective at trapping the target poisons which is easily detected by EPMA as shown in Figure 12.

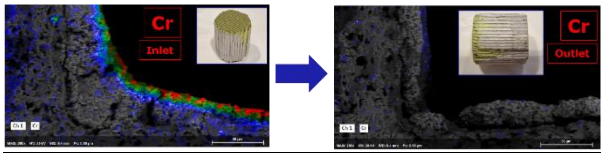

Figure 12. chromium deposition at the inlet of a trap

The interconnect getter technology has emerged as an industry preference, but stand-alone getter components upstream may also be required to enhance durability by protecting key components such as the catalytic combustor units.

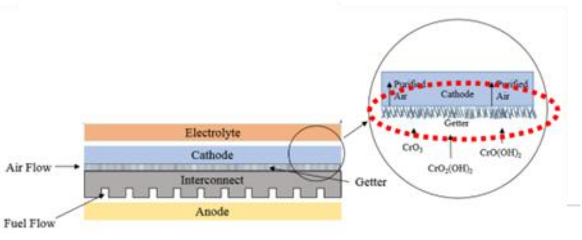

Figure 13a –Interconnect getter to trap chromium.

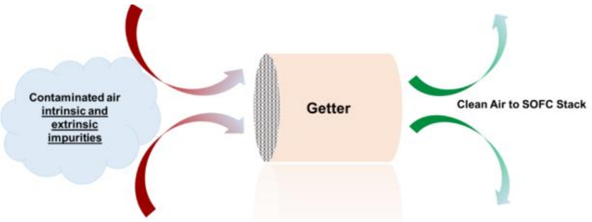

Figure 13b –Flow through getters to trap chromium.

This approach, utilising stand alone getters, will help prolong the integrity of the cell and offers a simpler mechanism for component change-out when the trap approaches saturation and in in need of exchange / regeneration. Supporting the efficient function of getters is a critical element of the modern fuel cell system and their design, protecting the essential processes and helping ensure efficiency and effectiveness as well as its evolving economics. Novel getter materials can be tested in dedicated rigs – to establish their effectiveness.

6.1 Experimental and Results

Figure 14 shows a laboratory test rig designed to study chromium poisoning, to test materials capability to act as protective getters.

Figure 14 – Test rig for chromium poisoning

The principle of the test is simple: to investigate how the getter performs at retaining chromium with varying temperature, flow rate and aging time. To minimise the impact of back pressure, these getter materials are coated or extruded honeycomb structures. The chromium content of the gas is determined pre (A) and post (B) getter using ICP and IC analysis. The getter efficiency Ef may then be determined

$$Ef = (1 - B/A)*100. \qquad (3)$$

SEM and cross-sectional characterization are important for quantifying the getters' performance.

Figure 15 shows test results for three materials and show trapping efficiencies in the range of 94 – 99% determined for some. The effectiveness of these traps is very dependent on the conditions, so the choice of optimum getter will be influenced by the fuel cells' operating conditions.

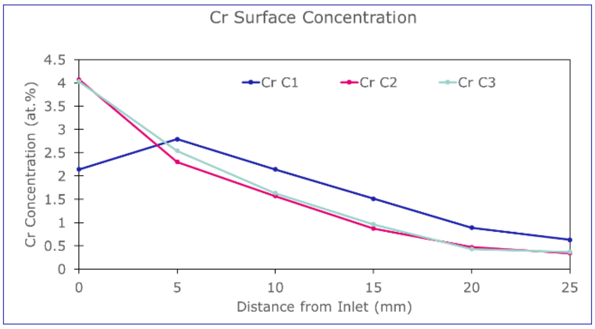

Figure 15. Measuring chromium poisoning

A comparison of combustion catalyst performance for poisoned and fresh catalyst is shown in Figure 16 illustrating the significant loss in activity.

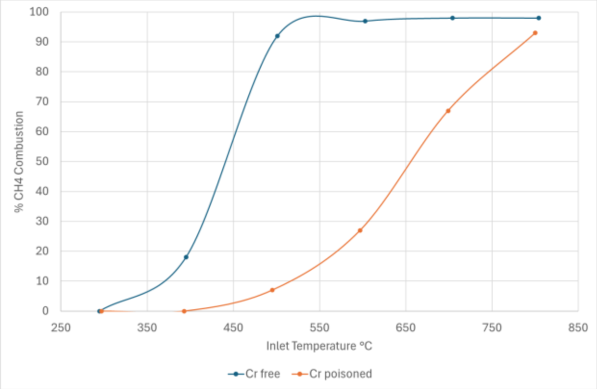

Figure 16. Impact of chromium poisoning on combustion catalyst activity

7 SUMMARY

Systems based on Solid Oxide Technology are sophisticated electrochemical devices, made ever more complex by the array for supporting components that facilitate the desired performance, such as lower carbon power generation. Operating at high temperatures this technology promises robustness and capability to operate with a suite of different fuels. For this concept of robustness to be realised and durable products more widely marketed, a greater understanding of supporting components both individually and collectively (the role it plays in the system) is required.

Key to improving durability is the treatment of undesirable species in the gas flow, the incoming fuel mix and outgoing flue gas. These include

- The effective reforming of Non-Methane HydroCarbons (NMHC) in the fuel to prevent substantive loss of catalytic activity through carbon deposition on active sites.
- Efficient and effective removal of unprocessed fuel which is crucial in ensuring environmental performance where the combustion catalyst technology should be assessed more for performance in real world conditions rather that an evaluation of start of life performance.
- Other undesirable species such as poisons e.g. chromium need to be trapped by "getter" devices – so that the electrochemical and other catalyst components are protected and permitted to function as designed for as long as possible.

The durability of Advanced Clean Energy Cells based on Solid Oxide technology is improving. A key role is being played by those engineers and chemists who consider the system as more than the sum of its parts. It is this open-minded and scientific approach that will capture synergy and accelerate the emergence of reliable, durable and economical solid oxide solutions.

8 ACKNOWLEDGMENTS

The authors would like to thank accessa (www.accessa.org) for support in drafting this paper.

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