Fast Gas Composition Analysis for Fuel Cell Development and Testing Using an Agilent Micro GC

Application Note

Micro Gas Chromatography, Fuel Cell Gases

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Abstract

This application note describes the use of an Agilent Micro GC for gas composition analysis during fuel cell research and development and *beta* testing. With three independently controlled column channels, the system provides a flexible setup for sample analysis at a number of points along the fuel gas line during fuel cell testing. As a result of short analysis times, fast and rich trend analysis data is available. This is important for quick and accurate diagnostic and QC testing. Moreover, its portability allows the Micro GC to be easily relocated to a different test stations.

Introduction

Worldwide demand for electricity is rapidly growing. Sustainable energy management including efficient and clean use of fossil fuels is therefore important. Ceramic Fuel Cells Limited (CFCL) is an Australian-based company developing fuel cells for residential and light commercial use to generate clean on-site electricity. A fuel cell turns energy stored in a fuel into direct electrical energy through an electrochemical process. A fuel cell produces its electricity cleanly and silently.

Unlike internal combustion engines and coal or gas powered turbines, fuel cells do not burn the fuel, thereby eliminating environmental unfriendly compounds. At CFCL, Solid Oxide Fuel Cells use natural gas as fuel. As a result, it can be connected to a regular natural gas network and does not need a separate hydrogen infrastructure to operate.

Instrument setup and conditions

Fuel cells, consisting of an electrolyte, a cathode, and an anode, produce heat and electricity through an electrochemical reaction. In the case of a Solid Oxide Fuel Cells (SOFC), electrical energy is produced at high temperatures from oxygen ions leaving the oxygen-rich cathode, passing through the electrolyte, and then joining hydrogen at the anode side [1]. A schematic setup of the fuel cell processes is given in Figure 1.

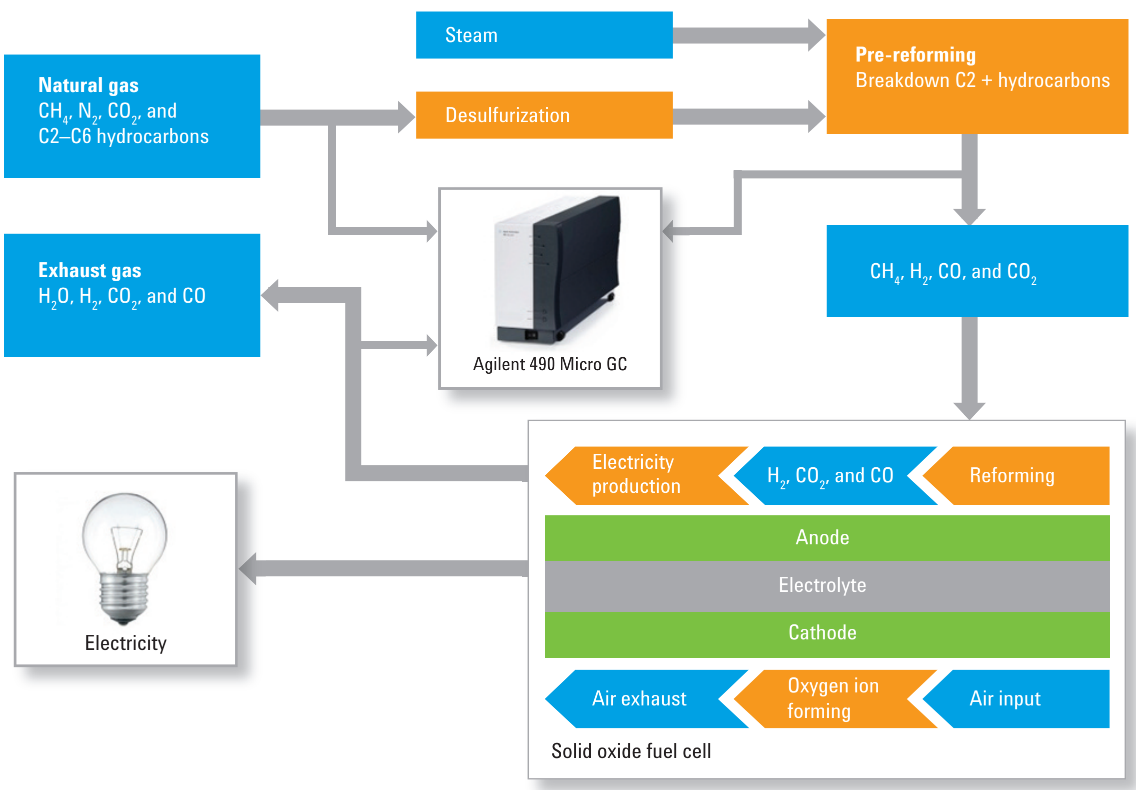

Figure 1. Fuel cell setup and sampling points for the Agilent 490 Micro GC.

Natural gas fuel is treated to remove sulfur compounds, then combined with steam to pre-reform C2+ hydrocarbons, leaving a methane-rich gas. The gas mixture then passes over the anode side, which reforms the methane gas under high temperature into hydrogen and carbon dioxide. High-temperature air is blown across the cathode, reducing the oxygen to oxygen ions. These oxygen ions travel through the electrolyte membrane and combine with hydrogen on the anode side to create an electric current, water, and heat. Most individual fuel cells produce less than 1 V during operation. To provide a useful voltage, multiple fuel cells are assembled in layers, forming a stack. Fuel cell stacks can continuously generate electricity as long as they have a supply of fuel and air. When a load, for example a light bulb, is connected between the anode and cathode, the circuit is completed, allowing the electrons to flow from the anode back to the cathode producing electricity.

CFCL uses the Agilent 490 Micro GC to analyze the gases at multiple stages in the fuel cell process during research and development and *beta* testing procedures. The instrument's shoe-box size dimension makes it easy to relocate the instrument when required. A sample was taken using the sampling pump built in the 490 Micro GC. Figure 1 shows the different sampling points representing the natural gas fuel feed, pre-reforming effluent, and final exhaust gas. The 490 Micro GC is equipped with three independently controlled analytical channels, which are used depending on the sample point and expected gas composition. These analytical channels include a molecular sieve (MS5A), a porous polymer (PPQ), and a 100% polydimethylsiloxane (CP-Sil 5 CB) column.

Settings for these columns and other system parameters are given in Table 1.

Table 1. Agilent 490 Micro GC parameters.

	CP-MolSieve 5A, 10 m	**PoraPLOT Q, 10 m**	**CP-Sil 5 CB, 4 m**
Column temperature	90 °C	60 °C	50 °C
Carrier gas	argon, 100 kPa	helium, 70 kPa	helium, 100 kpa
Injection time	40 ms	40 ms	40 ms
Backflush time	8 seconds	30 seconds	Not available
Sampling time	60 s (for all channels)		

Results and Discussion

Occasionally, the composition of the natural gas is checked by CFCL with the 490 Micro GC using three column channels. Chromatograms for all three columns are shown in Figure 2. To prevent destroying the pre-reformer catalyst as well as prevent poisoning the anode activity, sulfur compounds are removed from the natural gas before the gas is used as a fuel for the fuel cell stack.

Oxygen, nitrogen, and methane are analyzed on a MolSieve 5A. All other compounds, including moisture and carbon dioxide, are backflushed to vent to protect the analytical column. These compounds tend to adsorb quickly to the molecular sieve stationary phase changing its chromatographic properties. Over time, this would result in retention shifts and loss of separation [2]. The second channel, equipped with a PoraPLOT Q column separates and analyzes ethane, propane, and carbon dioxide. The C4+ hydrocarbons are backflushed to vent to prevent these compounds from interfering in succeeding analysis. A third channel with a CP-Sil 5 CB column is used to analyze the butanes, pentanes, and C6+ hydrocarbons.

Break-down of ethane and higher hydrocarbons, present in the natural gas, is accomplished by the pre-reforming process. The pre-reformer effluent gas stream includes mainly methane, hydrogen, carbon dioxide, and low levels of carbon monoxide. These compounds are analyzed on the Molecular Sieve 5A and PoraPLOT Q column channels to see whether the pre-reformer catalyst is working properly. The chromatograms for this sample stream are displayed in Figure 3. The total analysis time, approximately 3 minutes, is very fast. This results in fast and rich trend analysis data, which is important for fast and accurate diagnostic and QC testing of the fuel cell assemblies.

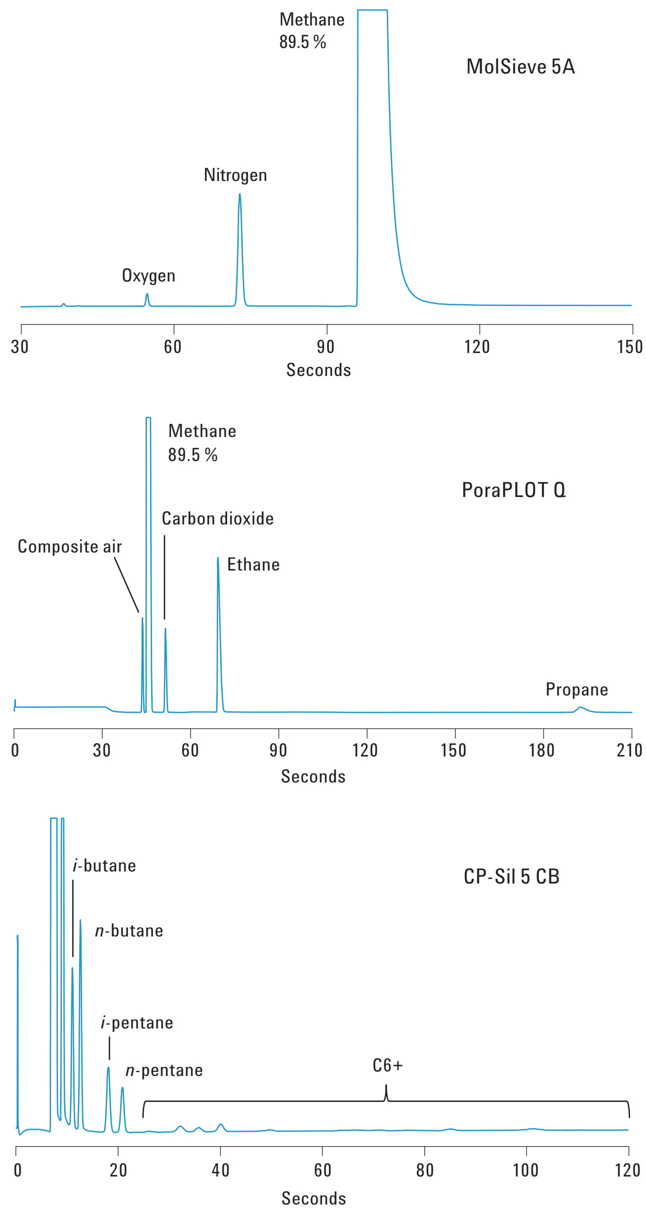

Figure 2. Compositional analysis of natural gas feed-in stream on MS5A, PPQ, and CP-Sil 5 CB column channels.

To further increase the hydrogen level, steam is added to the gas stream to convert methane into hydrogen. Hydrogen is formed by the water-gas shift reaction: oxidation of carbon monoxide. These chemical reactions take place during the internal reforming process at the fuel cell anode at high temperatures, approximately 750 °C.

$$CH_4 + H_2O \rightarrow CO + 3\,H_2$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

On the cathode side, high-temperature air is blown across the electrode. Oxygen from the air is reduced to form oxygen ions.

$$O_2 + 4\,e^- \rightarrow 2\,O^{2-}$$

These ions travel through the ceramic oxide electrolyte to the anode, where electricity is formed by an electrochemical reaction. Hydrogen and the oxygen ions are converted into water, heat, and electrons.

$$H_2 + O^{2-} \rightarrow H_2O + 2\,e^-$$

The anode exhaust gas is sampled and analyzed on a 490 Micro GC for multiple reasons; chromatograms are shown in Figure 4. First, the fuel cell's internal reforming process is verified. When reforming is efficient, very low methane levels are obtained.

Hydrogen uptake for calculating the fuel cell's efficiency is a second reason to analyze the composition of the exhaust gas. The 490 Micro GC analyzes hydrogen concentration during normal fuel cell operation. A comparison is made with the results when no current is drawn from the fuel cell.

Thirdly, nitrogen is measured to ensure the system has no leaks. Nitrogen levels in the exhaust gas are compared with the results found at the natural gas compositional analysis. Increased nitrogen levels indicate a leak in the fuel cell assembly.

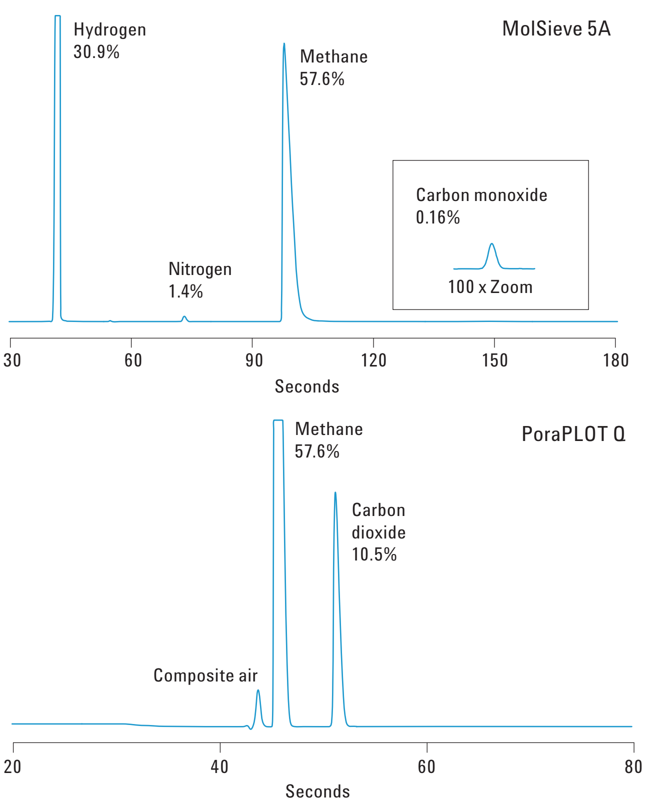

Figure 3. Pre-reformer effluent gas analyzed on MolSieve 5A and PoraPLOT Q.

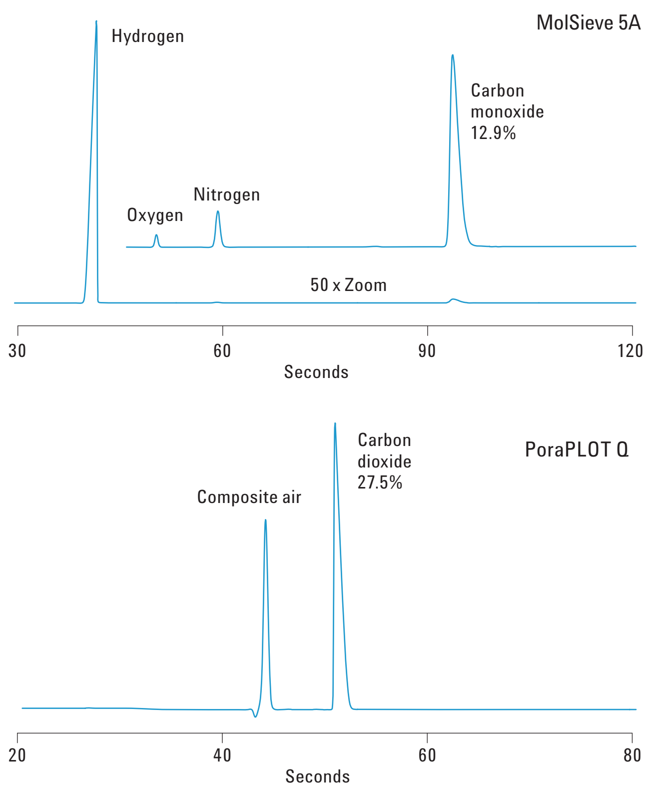

Figure 4. MolSieve 5A and PoraPLOT Q chromatogram for exhaust gas analysis.

Conclusion

This application note clearly shows the applicability of the Agilent 490 Micro GC for the analysis of fuel cell gases. A three channel setup, including a molecular sieve (MS5A), a porous polymer (PPQ), and a 100% polydimethylsiloxane (CP-Sil 5 CB) column, analyzes samples from multiple fuel cell processes. The system provides fast and accurate gas composition analysis for the natural gas used as fuel, the pre-reforming effluent, and the final exhaust gas.

The 490 Micro GC, with results in just minutes, leads to fast, accurate, and rich trend analysis data. For Ceramic Fuel Cells Limited (CFCL), a fast analysis time is very important for optimizing fuel cell efficiency during research and development and *beta* testing.

Portability is another reason CFCL chose a 490 Micro GC over a regular, benchtop gas chromatograph. As a result of the system's small form factor and low consumption of power and carrier gas, it can easily be moved from one test station to another. The optional portable field case, equipped with carrier gas supply and rechargeable batteries, increases the system's flexibility even more.

References

1. Fuel cell facts – Complete Set; Ceramic Fuel Cell Limited (CFCL); December 2011.
2. "Analysis of Biogas using the Agilent 490 Micro GC Biogas Analyzer" Agilent Technologies, Publication Number 5990-9508EN, November 2011.

For More Information

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