Catalysis of Nuvera On-Board Fuel Processor for Fuel Cell Vehicles

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Introduction

To lower greenhouse gas emissions and increase fuel utilization efficiency, many automotive and fuel cell companies are developing fuel cell technologies, however, the hydrogen infrastructure still does not exist. Construction of hydrogen production and fueling infrastructure is very costly and hydrogen storage technology remains as challenges today. Under the auspices of U.S. Department of Energy (DOE) and French car maker, Renault, Nuvera Fuel Cells have been developing on-board fuel processors for several years through continuous innovations focusing on catalyst selections, durability, control, power density, quick startup and fuel flexibility. Today, Renault continues to support Nuvera's developments of on-board fuel processor and power module, toward commercial vehicle power plant. This paper will focus on catalysis work of our on-board fuel processor.

Approach and Results

Catalysis Approach of Integrated Fuel Processor. Autothermal reforming (ATR) offers an advantageous alternative to steam reforming and POX for H_2 production for automotive fuel cell applications in terms of quick startup, heat management, fuel flexibility, compactness and durability. After careful studies, Nuvera adopted the approach based on the integration of ATR-HTS-LTS-PrOx-TGC reactors for the state-of-the-art Nuvera on-board fuel processor. The layout is shown in Figure 1, and the top view picture of the recently developed the state-of the-art onboard fuel processor is shown in Figure 2.

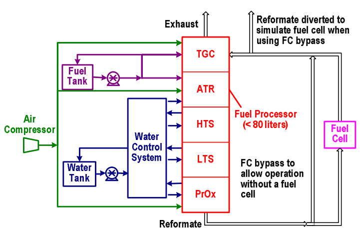

Figure 1. Layout of on-board fuel processor

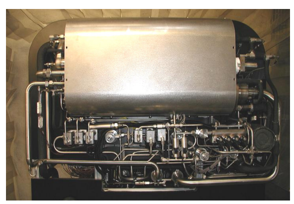

Figure 2. Picture of fuel processor

High Power Density and Compactness. The highly thermal integrated fuel processor is a very compact system. All the catalysts are coated onto substrates to give a high power density and low pressure drop. The total volume of reactors and heat exchangers for the recently developed system is only 80 liters with a maximum input power of 215 kW_{th}. The catalytic reactors, heat exchangers and balance of plant controls components may be packaged in a 150-liter volume designed to fit under the vehicle yielding a power density larger than 2 KW H_2/liter.

Fuel Flexible Capability. From the very beginning, we focused on catalyst technologies that had the capability to process multiple fuels, especially the ATR catalyst. The on-board fuel processor has been operated on gasoline, diesel, Jet fuel, ethanol, methanol and gas fuels, and can be either scaled up or down for other applications, for example, APU systems. The on-board fuel processors were also successfully integrated with Nuvera's automotive PEM fuel cell stacks.

Quick Starup. The utilizations of catalysts with low light-off temperature at ATR and WGS reactions zones and the ATR catalyst with low light-off temperature play a very important role for quick startups of on-board fuel processors. The startup on Nuvera's maximum 215 kW_{th} input on-board fuel processor shows that from 40 ^oC the sulfur free gasoline was sent to the ATR reaction zone at approximately 6 kW_{th} for 45 sec and then is increased to 40 kW_{th}. The CO level has dropped under the 100 ppm target at 1 minute and 24 seconds. After the CO drops under 100 ppm, it continues to decrease to as low 1 ppm with consistent control under 20 ppm while the hydrogen efficiency and hydrogen concentration ramp up to the steady state values. In just 6 years the startup time has been reduced from more than one hour to 1 minute and 24 seconds. This represents a 95% decrease as the technology has been adapted from an industrial process with large pellet-based catalyst to an automotive process with compact substrate-based catalysts, customized heat exchangers, and specialized controls strategies.

Durability. In order to achieve the near term goal of 3000 hours' durability at steady state and long term goal of 5000 hours of cycling. We have conducted catalyst durability studies both in micro-reactor scale for each of reaction zones as well as in a full-scale fuel processor. Our durability studies at different reaction zones shown In Figure 1 and at the integrated systems show that the chosen catalysts, feedstock mixing and distribution reactor set up and operating conditions and control play equally important role to achieve the durability goals, and our results indicate that the durability target is achievable.

Cost Reduction. The catalysts used at all of the reaction zones are based on the utilizations of precious metals (mainly Pt). The cost of precious metals in the catalyst is the major reason for the high prices of catalysts used in our fuel processors. Nuvera has collaborated with the catalyst suppliers, and has made some progress on the issues by increasing dispersion of precious metals, reducing the precious metal loading, doping transition metals synergistically, exploring new formulations that use cheaper precious metals. The recovery efficiency of the precious metals from the spent catalysis is >90%.

Steady State Validation Testing at On-Board Fuel Processor. The validation testing for the latest version of our on-board fuel processor shown in Figure 2 shows that the fuel processor has been carefully designed to cover a range of power conditions from 33 kW_{th} to 215 kW_{th} while maintaining CO below the 100 ppm target and hydrogen efficiency above the 77% target. The system achieves the full-power hydrogen efficiency with measured values of 79-80% at the PrOx exit. This corresponds to 1.4 g/s of hydrogen output. The hydrogen efficiency drops only 1-3% across the PrOx showing high selectivity for CO oxidation and a well designed reactor.

Catalyst Regeneration. In order to achieve the durability and cost goals, *in-situ* catalyst regeneration is an alternative strategy. On this subject, we have successfully developed methods for the involved catalyst zones.