Coatings for Compressor Seals

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National Renewable Energy Laboratory, Golden, Colorado

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Project End Date: April 3, 2020

Overall Objectives

- Improve the lifetime of seals used in hydrogen compression systems using GVD's conformal coatings.
- Demonstrate feasibility of a high throughput, mass manufacturing system for coated O-rings and seals.
- Demonstrate prolonged life of seals and gaskets in compression systems by increasing seal lubricity with a thermally initiated chemical vapor deposition poly(tetrafluoroethylene) (PTFE) coating.
- Optimize a flexible hydrogen barrier coating to be vacuum deposited onto elastomeric materials to reduce seal failure due to damage from hydrogen permeation.

Fiscal Year (FY) 2019 Objectives

- Quantify improved lifetime of PTFE-coated gaskets in hydrogen compressors.
- Optimize barrier coating structure and materials to maximize reduction in helium permeability on an elastomeric substrate.
- Expand network of industry partners for trialing PTFE-coated and barrier-coated seals.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan[1]:

- (B) Reliability and Costs of Gaseous Hydrogen Compression
- (I) Other Fueling Site/Terminal Operations
- (J) Hydrogen Leakage and Sensors.

Technical Targets

This project addresses the failure of seals in hydrogen compression, storage, and delivery operations. Large pressure and temperature variation in the hydrogen operation compromises seals and gaskets, as does frictional wear from motion and dimensional changes. PTFE lubricious coatings address failure due to friction wear on both hard plastic gaskets and elastomeric seals. Barrier film coatings address failures due to hydrogen permeation into elastomeric seal materials. Results are aggregated into Table 1.

The project goal is to increase the lifetime of seals and gaskets, thereby reducing leakages, failures, and maintenance downtime of systems. Success in this project will create significant movement toward the stated DOE goal of:

- By 2020, reduce the cost of hydrogen compression, storage, and dispensing at on-site production stations to <\$2.15/gge to meet the production and delivery cost target of <\$4/gge by 2020 (2007 dollars) (untaxed, delivered, dispensed).

FY 2019 Accomplishments

- Completed commercial sales of PTFE coatings for O-rings for hydrogen dispensing systems.
- Continued lifetime benchmarking of PTFE-coated seals in hydrogen compression at the National Renewable Energy Laboratory (NREL).

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

- Logged more than 600 hours of seal run time in lifetime benchmarking at Air Liquide hydrogen refueling station.
- Increased barrier coating performance to 80% reduction in helium permeability on silicone.
- Improved economics and reliability of barrier coating process by increasing the deposition zone size by 10x.

Table 1. Progress toward Meeting Technical Targets for Advanced Seal Coatings for Harsh Environments

Characteristic	Units	Current Status
Decrease in compressor gasket wear	Percent wear reduction (%)	70%
Compression gasket failure (incumbent benchmarking)	Pass/fail	Pass
Dispenser seal lifetimes	Relative lifetime	Testing in progress
Average permeation reduction (helium)	Percent reduction (%)	80%
Average permeation reduction (hydrogen)	Percent reduction (%)	N/A

INTRODUCTION

A critical obstacle to realizing the full potential of zero-emissions fuel cell electric vehicles (FCEVs) is the high cost for hydrogen compression, storage, and dispensing. Current hydrogen systems within FCEVs and the supporting infrastructure to compress, store, and deliver hydrogen fuel are prone to systemic inefficiencies and poor reliability. Many of these reliability problems stem from the failure of plastic and elastomer seals (including O-rings, gaskets, and piston seals), which results in significantly increased labor costs for rebuilds and excessive equipment downtime. One reason for seal failure is dimensional and mechanical change caused by saturation of the seal material by hydrogen molecules at high temperature and hydrogen pressure. Another important mechanism of failure is simple frictional wear, which stems from insufficient lubricity and is exacerbated by extreme temperatures and pressures. Thus, there is an urgent need for improved polymer seals with prolonged lifetimes and improved performance in extreme temperature (-40°C to 200°C) and high pressure (>875 bar) hydrogen environments to enable reliable operation of hydrogen systems. This need has been emphasized in meetings sponsored by DOE's Fuel Cell Technologies Office [1, 2], hydrogen compressor manufacturers, FCEV automakers, and two leading seal manufacturers. In this program, GVD addresses the challenges of hydrogen saturation and frictional wear using its proprietary lubricious coatings and gas barrier coatings.

APPROACH

This project aims to upgrade current state-of-the-art seals in hydrogen equipment by applying a vapor-deposited film on the outside of the seal. GVD is developing two specialized coatings for this objective (Figure 1). The first, a lubricious PTFE coating, is designed to reduce seal wear by providing a low-friction surface for seal motion. The second coating, a flexible gas barrier, is designed to restrict the transport of hydrogen into and out of seals during pressure swings to prevent the associated blistering and swelling.

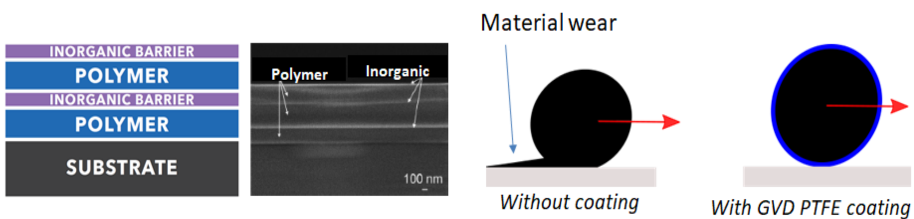

Figure 1. GVD is developing two coating classes to reduce the instances of seal failure in hydrogen compression equipment. Left: A flexible multilayer barrier coating reduces the transport rates of hydrogen into and out of elastomeric seals. Right: A lubricious PTFE coating mitigates frictional wear in seals that are "dynamic" (as in piston seals) or "static" (as in O-rings). Even in static seals, dimensional changes due to vibration, temperature swings, and hydrogen ingress can result in frictional wear.

To test its PTFE coatings as lubricating materials for compressor seals, GVD is partnering with equipment manufacturers (PowerTech, Takaishi Industry), end users (Air Liquide), and government labs (NREL) to directly measure the wear rates of coated seals in industrial hydrogen compressors and to determine the consequent increase in seal lifetime. In early phases of this program, GVD demonstrated that its coatings reduce the rate of mass loss of polymer gaskets in hydrogen compressors by 70%. In the current phase of the program, GVD is looking to further support the economic argument for its coatings by demonstrating a significant extension of lifetime of such seals as a result of reduced mass loss.

GVD's flexible barrier coatings utilize its proprietary methods for depositing flexible polymers and oxides via chemical vapor deposition. The coatings are being tested for their gas barrier properties using in-house helium testing; testing with high-pressure hydrogen is planned based on meeting a target helium permeability reduction of 90%. As part of the program, GVD has already designed a scaled-up coating tool that will be used to coat O-rings for use in hydrogen compressors.

RESULTS

GVD made its first commercial sales of its coatings in hydrogen applications in 2019. Demonstrations of improved seal wear rates early in this program helped GVD initiate trials of its lubricous coatings on elastomeric seals with Takaishi Industry in 2018. Takaishi Industry is a global seal company specializing in elastomers for hydrogen-specific equipment, such as breakaway fittings and compressor pistons. Positive results in trials with Takaishi led to two commercial orders in 2019. GVD is working with Takaishi Industry to explore more opportunities to add value to Takaishi's products in hydrogen compression, storage, and dispensing. Moving into dispensing equipment, where the operating temperatures are very low, represents a new subset of applications for GVD's coatings in the hydrogen delivery.

In 2019, GVD began a new testing partnership with Air Liquide. Air Liquide, which operates hydrogen refueling stations globally, is testing seals coated with GVD's PTFE in one of its California hydrogen refueling stations. Over the next 6–12 months, Air Liquide will run a total of four seal sets in various compression stages at its facility. The seals are installed in a Hofer compressor, operating 12–14 hours per day. A seal failure, in this case, is defined by exceeding a specified pressure leak rate between compressor use cycles. The average lifetime for seals at this location is between 1,100 and 1,200 hours. So far, Air Liquide has logged over 600 hours of operation on the first set of coated seals without observing seal failure and reports that the seals show significantly lower pressure leak rates than has been observed for uncoated seals. Lower leak rates are expected based on our previous data showing reduced seal mass loss and should precede a longer seal lifetime.

In collaboration with the Energy Systems Integration Facility at NREL, GVD continued lifetime benchmarking of PTFE-coated hydrogen compressor gaskets (Figure 2). NREL experienced the failure of a testing compressor (unrelated to the tested seals) at its hydrogen testing facility in January of 2019. After a full reconstruction of the testing compressor and required safety evaluations, testing has resumed as of August 2019. Currently, control seals installed at an NREL test compressor have run for 120 hours as of September 2019. The test compressor is operated 8 hours per day, and further automation is being explored to accelerate the testing. These seals will be run until they experience a failure, after which seals with a PTFE coating will be installed and run to failure to compare the lifetimes of the control and coated seals.

Figure 2. Left: Hydropac hydrogen compressor used to test GVD's PTFE-coated seals at NREL in Golden, Colorado. Right: a representative seal used in a hydrogen compressor.

In 2019, GVD continued the improvement of its gas barrier coatings by characterization of its vapor deposited polymer and oxide materials, as described in last year's Annual Progress Report. Based on chemical and morphological analysis, GVD refined the materials to give the most desirable properties in the multilayer hydrogen barrier coating. These include smoothness, uniformity, and flexibility for the polymer, and low defect density, low permeability, and uniformity for the oxide material. Combining the optimized materials, GVD then refined the number and thickness of the bilayers, which led to a coating that would reduce the helium permeation of an elastomeric substrate by 80% (Figure 3). This represents an improvement compared to the last iteration of the barrier coating, which was a 53% reduction. An 80% reduction in the rate of gas transport into and out of an elastomeric seal would significantly reduce the extent to which swelling and blistering would degrade the seal in the high-pressure hydrogen environment. In addition, GVD redesigned the gas flow characteristics of its deposition chamber (Figure 4) to increase the area of the deposition zone by 10x, which has the main effect of lowering the batch-to-batch variability of the process and reducing the per-part cost by increasing the allowable batch size.

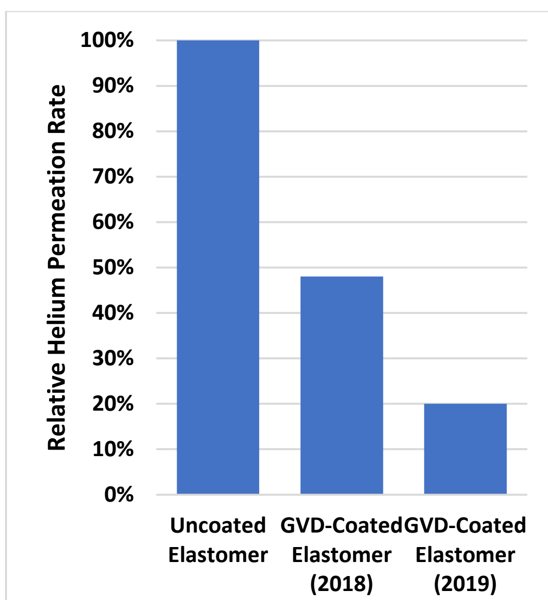

Figure 3. Helium permeability of an uncoated elastomer and an elastomer coated with GVD's gas barrier coating. In 2019, GVD improved the permeability reduction metric (vs. silicone substrate) from 53% to 80%, the main effect of which would be the reduction of damage of elastomeric seals by hydrogen-induced swelling and blistering.

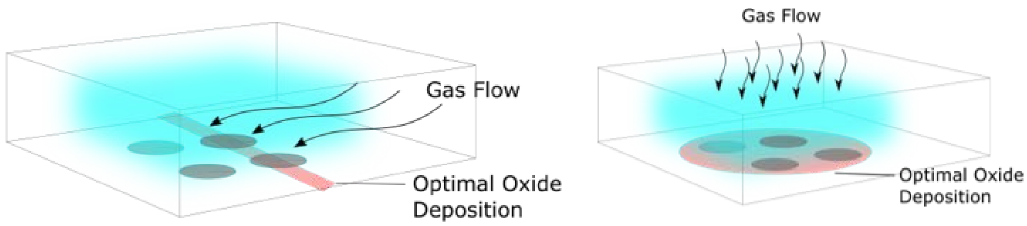

Figure 4. GVD optimized the gas flow characteristics in its deposition tool for the gas barrier coating deposition. By changing from lateral to top-down flow, GVD enlarged the deposition zone by a factor of 10, improving the reliability and lowering the per-part cost of the coating process.

To maximize the commercial impact of the DOE program, GVD is now consolidating its efforts in this program into the aforementioned testing of its PTFE coatings for compressor seals. The decision to focus on this area was based on the successful demonstrations of the PTFE coatings, a high level of interest from customers, and the anticipated amount of resources needed to gather essential data for discussions with potential customers. GVD's development work on the gas barrier coatings carried out in this program currently serves as the foundation for the development of similar coatings tailored to other applications in energy and electronics. A primary area of focus is using the gas barrier coatings to protect next-generation solar cells from water vapor during manufacturing (work supported by the DOE Solar Energy Technologies Office and the DOE Advanced Manufacturing Office).

CONCLUSIONS AND UPCOMING ACTIVITIES

In 2019, GVD improved the performance of its flexible gas barrier coatings for elastomeric seals and continued the testing of its lubricious coatings on polymer seals in hydrogen compressors, which included the addition of a new testing partner, Air Liquide. GVD also recorded its first commercial sales of its PTFE coatings for hydrogen equipment to Takaishi Industry. Takaishi and GVD continue to work together to expand the range of seal types that can benefit from a GVD coating. GVD will invest the remainder of its program resources in showing the reduced wear rate of PTFE-coated seals translates to an extension of seal lifetime, which would be a direct economic benefit of its coatings for end users of hydrogen equipment.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. Christopher Thompson, "Coatings for Compressor Seals." DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting, Arlington, VA, May 2019.

REFERENCES

1. *Polymer and Composite Materials Used in Hydrogen Service: Meeting Proceedings* (October 2012). Accessed August 20, 2013. http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/poly_comp_materials_proceedings.pdf.
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