

III.10 Hydrogen Pipeline Compressors

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Project Start Date: October 2006
 Project End Date: September 2012

Objectives

- Develop advanced materials and coatings for hydrogen pipeline compressors.
- Achieve greater reliability, efficiency, and lower capital investment and maintenance costs in hydrogen pipeline compressors.
- Research existing and novel hydrogen compression technologies that can improve reliability, eliminate contamination, and reduce cost.

Technical Barriers

The project addresses the following technical barrier from the Hydrogen Delivery section (3.2.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies (HFCIT) Program Multi-Year Research, Development and Demonstration Plan:

(B) Reliability and Costs of Hydrogen Compression

Technical Targets

This project is directed toward the study of fundamental mechanisms associated with the tribology of hydrogen pipeline compressors (friction, wear, and degradation). The goal of the research is to identify materials and engineered surface treatments that provide low friction and wear resistance required to achieve the energy efficiency and reliability targets for pipeline compressors. Accordingly, the project tasks address the challenges associated with meeting the DOE hydrogen delivery performance and cost targets for 2017:

Technical Targets for Hydrogen Delivery

Category	FY 2012 Targets	2008 Status
Reliability	Improved	Low
Energy Efficiency	98%	<98%
Total Capital Investment	\$12M	>\$15M
Maintenance	7%	>10%
Contamination	Varies	Unknown

Accomplishments

- A high-speed tribometer was converted to hydrogen use, and tests were started on baseline and coated specimens.
- High-speed, high-temperature tribometer specifications were drawn up and sent out for bid, and procurement was started.
- Tests in pure hydrogen were run to compare baseline materials and coated friction and wear behavior.



Introduction

Compressors are critical components used in the production and delivery of hydrogen. Current reciprocating compressors used for pipeline delivery of hydrogen are costly, are subject to excessive wear, have poor reliability, and often require the use of lubricants that can contaminate the hydrogen (used in fuel cells). Duplicate compressors maybe required to assure availability.

The primary objective of this project is to identify, and develop as required, advanced materials and coatings that can achieve the friction, wear, and reliability requirements for dynamically loaded components (seal and bearings) in high-temperature, high-pressure hydrogen environments prototypical of pipeline and forecourt compressor systems.

The DOE Strategic Directions for Hydrogen Delivery Workshop identified critical needs in the development of advanced hydrogen compressors – notably, the need to minimize moving parts and to address wear through new designs (centrifugal, linear, guided rotor, and electrochemical) and improved compressor materials. The DOE is supporting several compressor design studies on hydrogen pipeline compression specifically addressing oil-free designs that demonstrate compression in the 0-500 psig to 800-1,200

psig range with significant improvements in efficiency, contamination, and reliability/durability.

One of the designs by Mohawk Innovative Technologies Inc (MiTi[®]) involve using oil-free foil bearings and seals in a centrifugal compressor, and MiTi[®] identified the development of bearings, seals, and oil-free tribological coatings as crucial to the successful development of an advanced compressor [1]. MiTi[®] and ANL have developed potential coatings for these rigorous applications; however, the performance of these coatings (as well as the nickel-alloy substrates) in high-temperature, high-speed hydrogen environments is unknown at this point.

Approach

The approach that is being undertaken is to evaluate the tribological performance of seals and bearing materials under consideration by MiTi[®] and provide them with the data required to select the optimum seal and bearing material/coating configuration for a 300-kg/min centrifugal compressor that was designed in their Phase II studies. This effort will include: a) evaluating the effects of hydrogen environment on the mechanical properties of Ni alloys, b) evaluating the feasibility of coating suitable substrates with Argonne, MiTi[®], and outside vendor coatings, [2], c) establishing the requirements and testing needs for implementing near frictionless carbon (NFC) and MiTi[®]'s series of foil seal coatings, and d) evaluating foil seal and bearings under conditions prototypic of their proposed hydrogen compressor.

The research uses facilities and expertise at Argonne – notably the ability to deposit advanced high-performance coatings (NFC), to test and evaluate coatings under extreme conditions, and to characterize and understand friction, wear, and surface degradation phenomena that determine component lifetime and reliability.

Different contact stress/sliding speed regimes were identified depending on compressor design:

- Positive displacement - high contact stress, low sliding speed
- Axial flow compressors - high speed, low contact stresses
- Centrifugal compressors - intermediate speeds and contact stresses

Based on the range of contact stresses and sliding speeds anticipated for these compressors, we will replicate lab conditions to encompass nominal contact stresses between 2 and 1,500 psi, with sliding speeds from 0.1 to 10 m/s. Operating temperatures up to 500°C due to working-gas adiabatic heating and flash/asperity heating can add an additional 500 to 750°C

(depending on load, speed, thermal properties, and friction) to the temperature of near-surface asperities. Coating deposition focuses on NFC and also commercial coatings based on conventional solid lubricants. The substrates chosen are stainless, nickel alloys, and Cr-Mo steels.

The effect of gas composition has not been defined. Different levels of impurities (moisture, natural gas, contaminants) will affect formation of surface films. Lab tests will be performed with H₂ containing different levels of water and other trace impurities, and will use natural gas to establish the baseline performance of current compressors.

Results

During Fiscal Year 2008, tests were conducted to evaluate the friction and wear of candidate materials in both ambient and pure hydrogen environments, focusing on several candidate coatings. For baseline metals, serious wear occurs in open air environments as well as in H₂, with typical friction coefficients from 0.4 (Ti) to 0.7 (stainless). As is typical in dry sliding, galling and seizure are seen. Any lubricious oxides that may be present on the surfaces are reduced, allowing more direct metal-to-metal contact. A conventional MoS₂ coating produced a modest improvement in friction and wear and the Argonne-produced NFC coating showed quite low friction and wear and hydrogen seems to be beneficial (Figure 1).

A high-speed three-pin-on-disc tribometer was modified and updated for use with hydrogen (Figure 2). The system is capable of sliding loads prototypic of the centrifugal compressor seals under development by MiTi[®], but only at room temperature.

Shakedown tests of data acquisition and establishment of operating parameters were determined. A range of tests were performed using variable sliding (corresponding to rotor stop-start cycling) as well as variable load. Figure 3 shows the “transfer film” that forms when sliding coated materials seems to be an

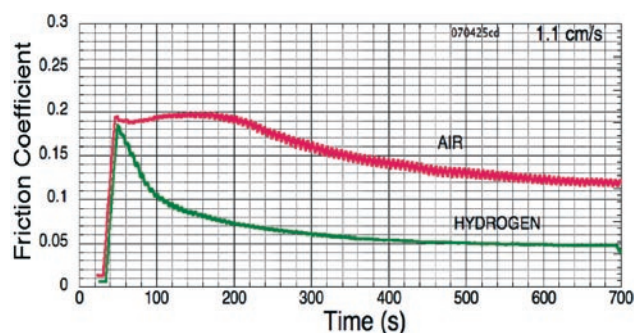


FIGURE 1. Friction as Function of Testing Time Using NFC-Coated M-50 Steel Against NFC-Coated X-750 Ni Alloy in Air (upper) and H₂ (lower)

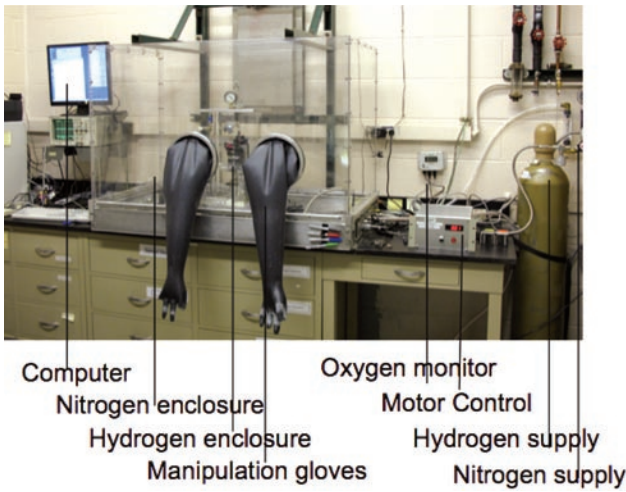


FIGURE 2. High Speed Hydrogen Test Rig

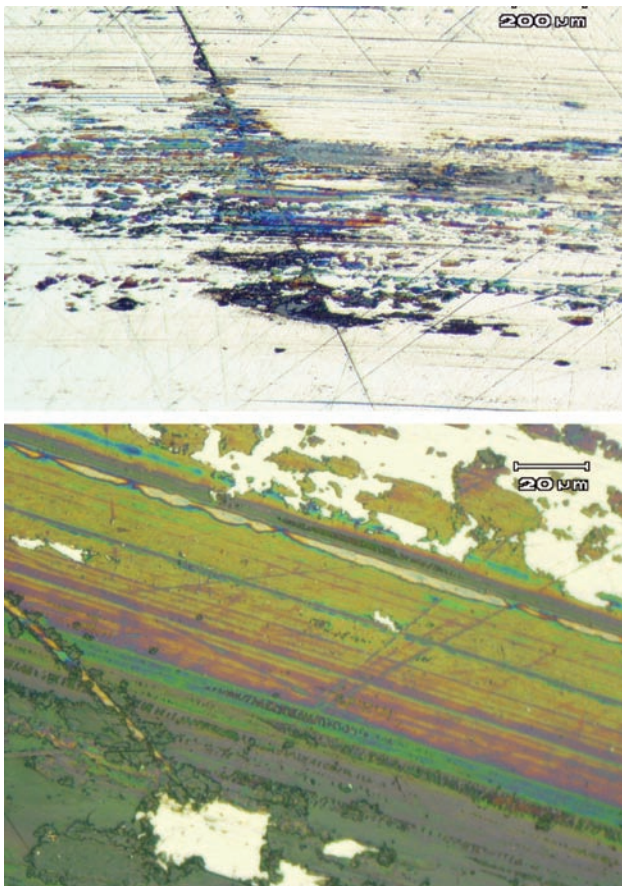


FIGURE 3. Low Magnification (top) and High Magnification (bottom) Micrographs Indicating Formation of Transfer Films, Which Seem to Promote Low Friction and Wear on DLC Materials

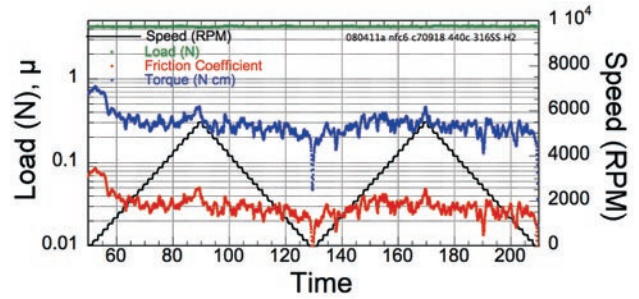


FIGURE 4. Friction as Function of Time and Speed, Showing Very Low Friction Behavior of NFC Coating for Ramps in Speed

effective method of lubrication when only one surface of the sliding couple is coated.

Figure 4 shows that even when subjected to high ramps in speed, the friction coefficient remains quite low.

This work has enabled a table of friction coefficients to be compiled (Table 1). The friction coefficients of sliding in nitrogen, N₂/H₂, and vacuum have been omitted because these are not relevant to the project, but are relevant for understanding the nature of the friction behavior.

TABLE 1. Friction Coefficients of Candidate Materials in Specified Environments

Material	Air	Hydrogen
Ni X-750	0.5-0.9	0.6-0.9
Ti alloy	0.4	0.5-2
316 steel	0.4-0.9	0.6-0.9
MoS ₂ /MoS ₂	0.25-0.5	-
MoS ₂ bond	-	0.2
MoS ₂ bond/ 316	-	0.1-0.2
DLC/316	0.2-0.4	0.03-0.04
DLC/DLC (pt contact)	0.1	0.04

A number of coatings have been identified as promising candidates, and each has features attractive for high-speed hydrogen use, but needs to be proven by testing. The coatings fall in the following areas:

- Composites such as Korolon, Molykote MoS₂/graphite.
- Intermetallics such as Tribaloy or WC+17%Co.
- Compounds such as BN composite, boride fused, MoS₂ or Bodycote.
- Carbon-based such as ANL DLC6, ANL N3FC, Ionbond, Diamonex, K-Systems DLC.

Conclusions and Future Directions

Considerable progress was made on establishing the tribological properties of baseline materials, and some coatings, in FY 2008. A total of 81 separate tests were performed, and the following conclusions reached:

- Baseline materials produce unacceptably high friction and wear.
- Some promising materials candidates were found, with DLC looking most favorable.

In FY 2009, room-temperature testing will continue to be performed by obtaining commercially available coatings in thick and thin film forms, which will be down-selected according to performance. A vendor for an elevated temperature test machine (to attain 500°C) was identified, and purchase and installation is scheduled for the first third of the FY.

FY 2008 Publications/Presentations

1. Friction and Wear Properties of Materials used in Hydrogen Service, R.A. Erck, G.R. Fenske, and O.L. Eryilmaz, presented at Materials Innovations in an Emerging Hydrogen Economy Conference, February 24-27, 2008, Cocoa Beach.
2. Friction and Wear of Metals and Coatings Used in Hydrogen Service, R.A. Erck, G.R. Fenske, and O.L. Eryilmaz, to be presented at 2008 International Hydrogen Conference Effects of Hydrogen on Materials, September 7–10, 2008, Jackson, WY.

References

1. H. Heshmat, P. Hryniewicz, J.F. Walton II, J.P. Willis, S. Jahanmir, and C. DellaCorte, *Tribol. Intl.* 38 1059–1075 (2005).
2. A. Erdemir, O.L. Eryilmaz, and G. Fenske, *J. Vac. Sci. Technol. A* 18(4) 1987-1992 (2000).