Novel Compression and Fueling Apparatus to Meet Hydrogen Vehicle Range Requirements

Todd Carlson
Future Energy Solutions
Air Products and Chemicals, Inc.
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Contributors:
David Chalk (Machinery Design)
Nick Pugliese (Fabrication)
Mark Rice (Controls)

Project ID: TV6

This presentation does not contain any proprietary or confidential information
Overview

- **Timeline**
  - Project Start 10/2002
  - Contract 5/2004
  - Project End 2/2006
  - 85% Complete

- **Barriers**
  - High cost of hydrogen compression
  - Cost of hydrogen

- **Budget**
  - Total $690,875
  - DOE Share $345,438
  - APCI Share $345,438
  - 04 Funding $317,606
  - 05 Funding $373,088

- **Collaboration**
  - Tescom
  - Genesys
  - Weh
  - OPW
  - Walther
  - Spir Star
Objectives

- **Primary**
  - Develop a process design for a novel compressor
  - Develop mechanical design for novel compressor
  - Select a test hydraulic fluid
  - Machine/Manufacture Compressor parts & components
  - Assemble prototype system and test
  - Demonstrate operation of the system
  - Final report

- **Secondary**
  - Investigate other fueling components to support 700 barg (10,000 psig) hydrogen fueling
Approach

- Conceptual Design
- Process Design
- Thermodynamic Data
- Fluid Selection and Testing
- Dynamic Modeling
- Component Design, Fabrication, and Testing
  - Machining of compressor parts complete
  - New valves developed for 15,000 psig
  - New relief valves being tested and qualified
  - New pressure switch identified
  - New thermocouple wells designed
- Prototype
  - Skid hazard review
  - Components on order for test skid
- Long Term Testing
  - Site selection and funding
Approach
Design Issues

- **Compressor**
  - Isothermal (~50 Deg F rise)
  - High pressure (~14,000 psig)
  - Single stage
  - Low cost

- **Fueling Station**
  - Lower the delivered cost of hydrogen
  - Composite vessels (ASME approval)
    - Lined steel vessels are $110,000/ft³ at 15000 psig
  - Breakaway and fuel nozzle (Walther, OPW, and Weh)
  - Fueling codes
Safety

- Air Products Hydrogen Experience
  - Over 12,000 fills (75-100/week)
  - 10 fuel stations installed last year (32 total, 12 in construction)
  - Industrial hydrogen (30+ years, 55% merchant market share, 1000 gaseous/500 liquid customers, pipelines, purification/separation, reformers, electrolysis)

- Our fueling systems have undergone rigorous third party independent safety reviews
  - ABS Consulting – Singapore
  - NASA - White Sands, NM
  - KHK/JHPGSL – Kagoshima, Japan
  - International Refinery Services – Singapore
  - Beijing Government – FSR Permitting
  - KGSL – Seoul, Korea
  - UL and Metlabs
## Timeline

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Technical Accomplishments
Novel Compressor – Basic Concept

- **Isothermal**: Gas cooled during compression (50 ºF rise)
- **Single Stage**: Liquid piston permits high pressure ratio by elimination of piston to cylinder clearance and temperature concerns (140:1 compression ratio)
- **Liquid Pump**: Inherently lubricates all dynamic seals
- **Dynamic Gas Seals Eliminated**: No gas seals to atmosphere
- **Issues**: fluid carryover, level control

many typical machinery issues eliminated by liquid piston
Technical Accomplishments
Existing Technology

- **Diaphragm Compressor**
  - Metal diaphragm separates gas from oil
  - 300 deg F temperature rise
  - 20:1 standard compression ratio
  - Up to 350 barg is bolted, higher pressure requires bootstrap

- **Hydraulic Intensifier**
  - Floating piston with rings separates gas from oil
  - 300 deg F temperature rise
  - 8:1 standard compression ratio
  - Smaller cylinder allows higher discharge pressures (long stroke at low RPM)
Technical Accomplishments
Cylinder Pressure and Temperature

~ 50°F temperature rise for 140:1 compression ratio
Technical Accomplishments
Cylinder Pressure and Temperature
Technical Accomplishments
Dynamic Simulation Results

- Identified key operational issues and design parameters:
  - Surface area requirements in heat exchanger and heat transfer coefficients for near isothermal operation
  - Liquid inventory management needs (pressure/flow regulation)

- Quantitative results on potential sources of inefficiency:
  - Hydraulic intensifier friction
  - Circuit DPs
  - Hydrogen solubility in compression fluid
  - Heat transfer limits and design of heat exchanger

- Process sensitivities to the following parameters studied:
  - Initial accumulator gas volume
  - Pump flow
  - Hydraulic intensifier flow
  - Valve flow coefficients

*novel H₂ compressor unit is feasible*
Technical Accomplishments
Pressure Analysis

- Automotive OEM’s are pursuing 700 barg fueling to achieve US norm of 300 mile range.
- Fast fill (~ 4-6 minutes) is the method with the highest commercial potential.
- Cascade fueling is the most often used method of achieving a low cost, fast fill. This is not possible at 700 barg with steel storage cylinders due to cost.
- To achieve full fills, cascade filling requires a minimum of 25% overpressure to counter vehicle tank heating.
- Fast fill to 700 barg will require cooling of the hydrogen.
- ASME and Air Products requirements for relief valves (set at vessel MAWP) impose a maximum operating pressure of 90% of MAWP.

\[
\frac{700 \text{ Barg} \times 125\%}{90\%} = 972 \text{ Barg MAWP (14100 psig)}
\]

System pressure requirement is 14100 psig MAWP
Technical Accomplishments
Fueling Apparatus

• Air Products has developed hydrogen fueling systems up to 700 barg (10,000 psig).
  – Valves
    • Manual
    • Actuated
    • Pressure Control
  – Flexible Hose
  – Tubing
  – Fittings and Adapters
  – Controller
  – Packaging

Most components available today for 700 barg fueling
Responses to Questions

- What fluid is used for a compressor?
  - Krytox Fluorocarbon Oil
  - Patents are submitted and contract with DOE and DEP are now signed
Future Work

- Assemble and Test.
- Determine overall costs.
- Determine feasibility of future use.
- Long term prototype testing, if warranted.
- Final Report
Interactions/Collaborations

- Air Products and Chemicals, Inc.
  - Future Energy Solutions
  - Advanced Systems Machinery
  - Advanced Controls
  - Dynamic Modeling
  - Corporate Safety
- Tescom
- Spir Star
- Barksdale
- Ashcroft
- Weh
- OPW
- Walther
Questions?
Thank you
tell me more
www.airproducts.com
Publications and Presentations

- May 2003 – DOE Peer Review
- May 2004 – DOE Peer Review
Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

**Drawing air into the compressor suction and compressing into the high pressure hydrogen storage vessels. Given the correct conditions, this could result in a high pressure flammable gas mix. Deflagration or detonation of this mixture could result in failure of the vessels.**
Hydrogen Safety

Our approach to deal with this hazard is:

*We have completed a Level of Protection Analysis that takes all physical and operating conditions into consideration to determine the probability of the event occurring. We also utilize a low pressure switch on the compressor inlet (hard-wired to PLC power). This pressure switch is functionally tested every quarter.*