Novel Compression and Fueling Apparatus to Meet Hydrogen Vehicle Range Requirements

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Project ID: TVP3

This presentation does not contain any proprietary or confidential information
Overview

- **Timeline**
  - Project Start 10/2002
  - Contract 5/2004
  - 90% 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
  - 06 Funding – Earmark for continued development

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

● Primary
  – Develop a process design for a novel compressor to achieve near isothermal compression in a single cylinder with a compression ratio of 140:1
  – 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
- Prototype
  - Site selected and compressor installed
  - Components in hand for test skid
- Long Term Testing
  - Site selection
  - Funding has been granted
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
    - Alternate materials suitable for high pressure hydrogen service are high cost and difficult to machine.
  - Breakaway and fuel nozzle (Walther, OPW, and Weh)
  - Fueling codes
Safety

- Air Products Hydrogen Experience
  - Over 20,000 fills (75-100/week)
  - 8 fuel stations installed last year (40 total, 10 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
  - BP – PHSER review
  - NASA - White Sands, NM
  - KHK/JHPGSL – Kagoshima, Japan
  - International Refinery Services – Singapore
  - Beijing Government – FSR Permitting
  - KGSL – Seoul, Korea
  - UL and Metlabs
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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).
- **Simple Fabrication**: No exotic materials or sophisticated machining.
- **Liquid Pump**: Inherently lubricates all dynamic seals, off the shelf pump
- **Small Footprint**: 3’x4’x7’
- **No External Cooling**: Radiator on hydraulic loop is all that is needed
- **Dynamic Gas Seals Eliminated**: No gas seals to atmosphere
- **Level Control**: Density control
- **Potential Issues**: Fluid carryover, high pressure storage vessels, intensifier seal wear

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

~ 50ºF temperature rise for 140:1 compression ratio
Technical Accomplishments
Cylinder Pressure and Temperature

![Graph showing cylinder pressure over time](image-url)
**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

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*novel $H_2$ 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 and hydrogen embrittlement concerns.
- 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 and communications between the vehicle and dispenser.
- ASME and Air Products requirements for relief valves (set at vessel MAWP) impose a maximum operating pressure of 90% of MAWP.

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

System pressure requirement is 14100 psig MAWP
Technical Accomplishments

Cost / Efficiency

<table>
<thead>
<tr>
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<th>Today</th>
<th>Novel Compressor Prototype</th>
<th>Novel Compressor “Product” (10 per year)</th>
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<tr>
<td><strong>Cost</strong></td>
<td>$1.00</td>
<td>$.40 - $.50</td>
<td>$.25 - $.30</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td></td>
<td>In principle, will require less power. Testing to determine.</td>
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Flow = 70 scfh H2  
Pin = 100 psig  
Pout = 14,000 psig
Technical Accomplishments
Dispenser Update

- Dispensers have been updated to include a breakaway and nozzle shield.
- New HMI touchscreen allows use of a single panel for control and display.
- Class I Division 1, Group B design for dispenser.
- Control panel is separate enclosure rated for Class I Division 2, Group B.
- Dispenser components upgraded to 15,000 psig MAWP (700 barg).
- Fueling hose with 6:1 safety factor.
- New remote data acquisition system is being piloted (e-Ram).
Future Work

- Long term operational test.
- Determine overall costs.
- Determine feasibility of future use.
- Identify barriers and other work needed for 700 barg fueling.
- Final Report
Summary

Relevance: Develop a compressor that enables 700 barg fueling by lowering the cost of hydrogen.

Approach: Design a compressor that can dramatically lower the cost, maintenance, and power requirements for fueling.

Accomplishments: Developed a 700 barg dispensing system. Compressor is built and undergoing testing.

Collaborations: Work with industry leaders and develop required hardware to support 700 barg fueling.

Future: Continued testing and installation into a fueling station.
Interactions/Collaborations

- Air Products and Chemicals, Inc.
  - Future Energy Solutions
  - Advanced Systems Machinery
  - Advanced Controls
  - Cryomachinery
  - Dynamic Modeling
  - Corporate Safety

- Tescom
- Spir Star
- Barksdale
- Ashcroft
- Weh
- OPW
- Walther
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Response to 2005 Reviewer’s Comments

- Potential hurdles not identified.
  
  We are working to identify the potential hurdles to compressor operation. A test plan will be executed to check each portion of the system prior to full operation.
Publications and Presentations

- May 2003 – DOE Peer Review
- May 2004 – DOE Peer Review
- May 2005 – DOE Peer Review
Issues

- Determined that the original Krytox oil could react with hydrogen. Switched to a mineral oil that is much lower cost and will act as a better lubricant.

- Identified some problem materials (17-4 ph steel) used for trim on some valves. Identified an alternate heat treatment to repair the items, if they have not been in hydrogen service.

- Will investigate other fluids and absorption vessels. There is potential for vapor carryover of the mineral oil.

- Need to monitor the intensifier seal rings for wear and check coalescer for wear products.

- Medium pressure component lead times have gone to 4x normal due to Hurricane Katrina and the rebuilding effort.
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.