Pressure Vessels for Hydrogen Vehicles: An OEM Perspective

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700 bar type IV vessels

- Applications
- Technology
- Refueling
- Testing
- Real World Validation
- Standards / Regulations for next Vessel Generation
- China specific items
700 bar type IV vessels – History in GM FCEVs

- HydroGen3
- Hy-wire
- AUTOonomy
- Sequel
- Equinox FC
700 bar type IV vessels used in world’s largest FCEV fleet

Equinox FC Application

- World’s largest market test with over 100 vehicles deployed on the road
- Gain real world experience and feedback on fuel cell vehicles and hydrogen refueling
- Deployment locations:
  - USA: California, New York, Washington D.C.
  - Europe: Berlin
  - Asia: Korea, China
700 bar type IV vessels - outline

Equinox FC Technology

- 3 Vessel System
- Type: Carbon fiber composite
- Service pressure: 700 bars
- Storage capacity: 4.2 kg CGH₂
GM/SAIC EXPO FCEV Collaboration

• GM/SAIC are providing the jointly developed “Shanghai FCV” based on SAIC’s Roewe 750 model to EXPO 2010
• Vehicle uses modified Fuel Cell Propulsion System out of the Chevrolet Equinox FC
  • Includes 70MPa capable Type4 tank system
Energy implications of 700 bar storage systems

- **350 bar**
  - 4kg Hydrogen
  - 133 kWh
  - + 10% compression energy
  - + 55% energy content

- **700 bar**
  - 6.2kg Hydrogen
  - 207 kWh

• Most compression energy is expended at lower pressures
• **10%** additional compression energy to get from 350 bar to 700 bar...
• ...leads to **55%** increase in energy content
700 bar type IV vessels - details

Equinox FC Technology

- Foam dome
- Protection layer (glass fibers/epoxy)
- Reinforcement (carbon fibers/epoxy)
- Liner (HDPE)
- Polar end boss (Steel)
700 bar type IV vessels compared to type III vessels

Compared to Type III Vessels, Type IV Vessels have
- 20% lower weight with identical volumetric storage density
- higher potential regarding long term fatigue and durability (little/no liner cracking)
- lower cost carbon fibers (lower E-module)
Hydrogen Storage System cost reduction - Finite Element modeling

- Predictive FE models generate material-cost optimized designs and manufacturing processes
- Composite material experiments feed virtual design optimization cycles
- Virtual design cycles reduce build and test time of vessel prototypes
Project Driveway Learning – Refueling Time

“The fueling process is lengthy, though the staff are EXCELLENT and make the time seem short with healthy conversation and great interaction.”

- Project Driveway refueling time < 4 min validated at GM proving ground station
- All stations in Germany with -40°C precooling: 4 current, add. in 2010
Refueling Time: SAE J2601 A (-40ºC) vs. B (-20ºC)

<table>
<thead>
<tr>
<th>Ambient Temperature, T (°C)</th>
<th>Initial Tank Pressure, P0 (MPa)</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>50</td>
<td>6.3</td>
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<td>&lt; -40</td>
<td>no fueling</td>
</tr>
</tbody>
</table>

Add intermediate leak check times: up to 10 sec after every 3MPa increase in fueling pressure.

-40ºC: 1.8 – 2.9 min

-20ºC: 3.9 – 15.7 mi

• -40ºC is a significant enabler for customer acceptance of Hydrogen refueling
Letter of Understanding Signed – 08SEP09
Automotive Industry Support for Battery & Fuel Cell Technology

Letter of Understanding
on the Development and Market Introduction of Fuel Cell Vehicles

To: Oil and Energy Companies, Government Organizations and NOW GmbH

• Battery and fuel cell vehicles complement each other
• 2015 FCEV commercialization anticipated
• Hydrogen infrastructure with sufficient density required by 2015
• Built up from metropolitan areas via corridors into area-wide coverage
• Stations integrated into branded conventional stations, meet SAEJ2601 requirements, and offer hydrogen at a reasonable price to the customers
Increased Range through Communication Fill

Hydrogen Storage System Fueling Window and SOC range (700 bar)

- Communication Fueling:
  - Always near 100% SOC

- Non-Communication Fueling:
  - Near 100% SOC in best case
  - As low as 84% SOC in worst case
  - Typically somewhere in between

Vehicle data allows station to target 100% SOC, increasing real-world range of the fuel cell vehicle.
700 bar type IV vessels - refueling

Equinox FC Refueling

Customer friendly fueling:

- One single physical connection
- Infrared communication interface (tank pressure/temperature)
- Fast fill: 3 min. at -40°C pre-cooling
- Automatic data transfer via WLAN to Engineering team
700 bar type IV vessels - tests

Equinox FC Testing

- Certification according to Draft ECE Compressed Gaseous Hydrogen Regulation Revision 12b, 12.10.03

- Following test were successfully conducted with 700 bar type IV Vessels:

  ✓ Tests of raw material
  ✓ Corrosion test
  ✓ Hydraulic pressure test
  ✓ Burst test
  ✓ Cycle test (ambient temperature)
  ✓ Cycle test (extreme temperature)
  ✓ Leak before break test
  ✓ Chemical exposure test
  ✓ Bonfire test
  ✓ Penetration (bullet) test
  ✓ Composite flaw tolerance test
  ✓ Accelerated stress rupture test
  ✓ Impact damage (drop) test
  ✓ Leak test
  ✓ Permeation test
  ✓ Boss torque test
  ✓ Hydrogen cycle test
Equinox FC Statistics
(status: Sep. 8th, 2010)

- Start of operation: Mid of 2007
- Current fleet: 117 vehicles
- Total mileage of Equinox vehicles: 1,665,602 miles
- Total refueling counter: 20,404
700 bar type IV vessels – standards and regulations

Standards / Regulations for next Vessel Generation

Next generation of Type VI Vessel shall be certified / tested according to following standards / regulations:

- EC 79-2009 EU H2 Regulation

- EC 406-2010, Implementation Regulation

- HGV 2 Draft
  COMPRESSED HYDROGEN GAS VEHICLE (HGV) FUEL CONTAINERS

- ISO 15869
  Gaseous hydrogen and hydrogen blends — Land vehicle fuel tanks

- SAE J 2579
  COMPRESSED HYDROGEN VEHICLE FUEL CONTAINERS
Open items China, Global

- Type IV vessel operation
- 700bar pressure
- Test facilities which deliver same results around the globe
- Globally harmonized codes and standards for on-vehicle H2 storage
- Globally harmonized filling protocols and interfaces
- Globally harmonized H2 vehicle certification and process
Ideal solution from automotive company perspective

Goal:
• tank systems certified in one country to be allowed in other countries
• supplier based development on global basis

• Test protocols and requirements to be harmonized with global standards, ISO, SAE and Global Technical Regulations (GTR) for on-board vessel, interface, filling protocols, etc.
• Established testing facilities that are fully efficient in performing tests and validation.
  • Test data to be interchangeable with data performed in other countries
• Need special process to permit small volume operation (demo, pre-commercial phase).
• Trigger discussion of requirements for Infrastructure to meet vehicle level requirements