Benefits of Steel Fuel Tanks for Gasoline-Powered and Hybrid Vehicles

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Outline

- Historical Perspective of steel and plastic tanks
- Outdated Perceptions of steel tanks
- Some Key Features and Attributes of Steel Tanks
  - Cost competitiveness and availability
  - Mass
  - Fuel Capacity
  - Evaporative Emissions
  - Durability
  - Design flexibility
  - Sustainability/recycling
- Steel Tanks for Hybrid Vehicles
Introduction

• For most of the history of the automobile, steel fuel tanks have been used:
  – Effective container
  – Safe
  – Easily manufactured
  – Durable
  – Recycled
• In recent decades, plastic fuel tanks have emerged and grown market share
• Improved features of the steel tank and new market requirements have increased steel competitiveness
• Latest generation hybrid-electric fuel systems present unique challenges that are well-matched to steel’s advantages
Historical Perspectives

- **Monolayer, HDPE plastic tanks** emerged in Europe in the 1970’s
  - Blow-molded
  - Lower cost than steel
    - **BUT .....** *Highly permeable, allowing evaporative emissions*
    - *Fluorination and sulphonation helped reduce emissions*
- **Multilayer HDPE plastic tanks** were then developed
  - Blow-molded
  - Favored in North America (lower emissions)
    - **BUT .....** *More complex structure/molding increased costs*
- **Environmental issues** (from 1990s)
  - Stricter regulations on evaporative emissions (EPA, CARB, Euro V)
    - **EFFECT .....** *More complex plastics/manufacturing increases plastic tank costs*
  - Growing requirement for recycling (especially Europe)
- **Advent of alternative fuels/power systems**
  - Alcohol-containing fuels (E10 to E100). *Impact on emissions and driving range*
  - Bio-diesel fuels (B10 to B90). *Impact on durability*
  - Hybrid vehicles. *New requirements for evaporative emissions control, NVH*
Outdated Perceptions of Steel Fuel Tanks

... “Always more costly”
... “Less design flexibility”
... “Have higher mass”
... “Simple shapes minimize fuel capacity”
... “Steel rusts and corrodes”

Based on new steels and tank manufacturing processes, these are Misperceptions and...
Benefits of Steel Fuel Tanks

- Impermeability is ideal for meeting low evaporative emission requirements (e.g. PZEV)
- Highly formable steels & improved manufacturing allow:
  - Complex shapes
  - Increased fuel capacity
- New steel ‘systems’ are:
  - Resistant to external corrosion (beyond 15 years / 150,000 miles)
  - Compatible with alternative fuels
- High rigidity for good shape stability
As technical requirements for fuel tanks have increased, the cost competitiveness of steel tanks has increased.
HDPE resin prices are increasing much faster than steel due to global oil price rises.

Materials Price Trends as of 01/11/2008

'INSTABILITY'

Crude Oil - NY Mercantile Exchange (NYMEX.com) - US dollars / barrel
HDPE - Plastic News (plasticsnews.com) - US cents / pound
Steel Electrogalvanized - American Metal Market (amm.com) - US dollars / CWT
**EXAMPLE:** Recent SASFT comparative design – AWD Saddle Tank

<table>
<thead>
<tr>
<th>Steel System</th>
<th>Plastic System</th>
<th>Mass Savings with Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Steel Thickness (mm)</strong></td>
<td><strong>(Shell &amp; Shield)</strong></td>
<td><strong>(lbs.)</strong></td>
</tr>
<tr>
<td>Top</td>
<td>Bottom</td>
<td>Mass</td>
</tr>
<tr>
<td>Option A</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Option B</td>
<td>0.7</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Because the steel tank also had higher fuel capacity, resizing the steel tank to provide the same fuel capacity as the plastic version would save additional mass.
### Case Study: Fuel Tank System

**Fuel Capacity Optimization**

<table>
<thead>
<tr>
<th>Steel Tank</th>
<th>Plastic Tank</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>85.16 liters</td>
<td>79.46 liters</td>
<td>5.7 liters (1.5 gallons) or 7%</td>
</tr>
<tr>
<td>(22.5 gallons)</td>
<td>(21.0 gallons)</td>
<td></td>
</tr>
</tbody>
</table>

**EXAMPLE:** Recent SASFT comparative design – AWD Saddle Tank

Steel tanks can have a fuel capacity advantage.
Steel is impermeable to gasoline, alcohol, diesel, and bio-diesel • • • ideal for low evaporative emission requirements

Steel Fuel Tanks — the choice for PZEV

Steel Fuel Tanks . . . the choice for PZEV vehicles

California Air Resources Board:
— Certified gasoline PZEV models
  • 14 in 2003
  • 23 in 2004
  • 29 in 2005
  • 40 in 2006

CARB PZEV certified vehicles for 2006

<table>
<thead>
<tr>
<th>Company</th>
<th>Model Year</th>
<th>Model Name/Type</th>
<th>Emission Rating</th>
<th>Tank Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ford</td>
<td>2005</td>
<td>Escape – Hybrid 2WD, 4WD</td>
<td>ATPZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>Focus – Wagon - 2X3/2X4/2X5</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>Fusion</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td>DaimlerChrysler</td>
<td>2004</td>
<td>Sebring – Sedan</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Stratus – Sedan</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>325C1 – Coupe</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>3251 – Sedan</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>3251 – Wagon</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td>Chrysler</td>
<td>2004</td>
<td>Sebring – Hybrid</td>
<td>ATPZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Accord – EX/LX Sedan</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td>Hyundai – Kia</td>
<td>2005</td>
<td>Elantra – GLS &amp; GT</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>Spectra – 2.0L</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Mazda 3 – 2.0L/2.3L</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>Mazda 6 – 2.3L</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>Tribute HEV-4WD</td>
<td>ATPZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>E350 – 3.5L</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td>Mitsubishi</td>
<td>2006</td>
<td>Lancer 2.0 and 2.4L</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>Galant DE &amp; ES2.4L</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Altima 2.5, 2.5S, 2.5SL</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Sentra 1.8, 1.85</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td>Toyota</td>
<td>2004</td>
<td>Legacy 2.5 GT Sedan</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Legacy 2.5 GT Wagon</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Legacy 1 Sedan/Wagon</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Outback Ltd Sedan/Wagon</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Camry LE, SE or XLE</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>Prius – Hybrid</td>
<td>ATPZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>S60 2.4 Sedan</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>V70 2.4 Wagon</td>
<td>PZEV</td>
<td>Steel</td>
</tr>
</tbody>
</table>
Total permeation (HC and Ethanol) in plastic systems increases with low ethanol additions.

Source: Coleman Jones, GM presentation at ITB Fuel Systems Conference (March 2, 2007)
Permeation in plastic can be exacerbated by the presence of water in alcohol-containing fuels.

Source: GTR Tec measurements of permeation through 6-layer plastic tank material (presented at Yokohama Conference in 2007)
Steel Fuel Tanks for Hybrid Vehicles
Hybrid (Gas/Electric) Vehicles

- Hybrids have become popular, particularly in North America
  - "Green" technology
  - Low cost of ownership
    - Reduced fuel consumption
    - Good resale value
  - Help OEMs meet CAFÉ and emissions requirements
- Provide unique challenges to fuel system design
Regulatory Considerations

• California requires OEMs to produce increasing numbers of vehicles which earn ZEV (Zero Emissions Vehicle) credits
  – Connecticut, Maine, Massachusetts, New York, Pennsylvania, Rhode Island and Vermont currently use California’s emissions laws, and about a dozen other states intend to adopt it (pending legal action regarding CO₂ requirements)

• 3 ZEV Categories, with different credit levels
  – “Gold”: Pure ZEV, e.g. Battery electric or Fuel cell
  – “Silver”: Uses ZEV enabling technologies, with emissions equal to or below “Bronze” level (a.k.a. AT-PZEV)
  – “Bronze”: SULEV exhaust emissions with “zero” fuel evaporative emissions (a.k.a. PZEV)

• Hybrid vehicles can earn “Silver” credits
ZEV “Silver” Credits for Hybrids

- Total credit determined by:
  - PZEV “base” = 0.2
  - Zero Emissions Range
    - Ranges from 1.1 credits for 10 miles range, to 2.25 credits at 90 or more miles
  - Advanced Componentry
    - Up to 0.5 credits for full hybrids
    - 0.1 additional credit for plug-in hybrids
  - Low Fuel Cycle Emissions
    - Plug-in hybrids can earn up to 0.15 credits

- Hybrids can earn up to 3 credits per vehicle (equivalent to 15 PZEV vehicles) – Zero Emissions Range is the key to highest credit potential
## Characteristics of Hybrids

<table>
<thead>
<tr>
<th>Feature</th>
<th>Conventional Vehicle</th>
<th>Mild Hybrid</th>
<th>Full Hybrid</th>
<th>Plug-In Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuts off the engine at stop-lights and stop-and-go traffic</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Uses regenerative braking and operates above 60 volts</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Uses an electric motor to assist a conventional engine</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Can drive at times using only the electric motor</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Recharges batteries using electricity from the wall plug and has a significant operating range on electricity alone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity for purging fuel vapors stored in carbon canister</td>
<td>Baseline</td>
<td>Slightly Reduced</td>
<td>Significantly Reduced</td>
<td>Potentially Zero</td>
</tr>
</tbody>
</table>

Source: www.hybridcenter.org
• Hybrid vehicles with all-electric driving range cannot easily purge fuel vapors stored in the vehicle’s carbon canister during:
  – Refueling (Onboard Refueling Vapor Recovery)
  – Evaporation in vehicle operation or parking / diurnal temperature swings
• Several OEMs are employing “sealed” fuel tanks to enable reduction of vapor generation
  – e.g. Toyota Highlander, Camry, etc.
Design goals:

– Zero evaporative emissions for AT-PZEV
  • Typical SHED emissions less than 15 mg/day using test fuel

– Sealed high-pressure/vacuum architecture
  • Requires high strength and stiffness at all working temperatures

– Stringent NVH targets
  • Must accommodate anti-slosh baffles if required

• **Steel provides optimal performance to requirements**
Conventional ORVR System
“Normally-Closed” Hybrid System

NOTE: Depending on OEM preferences / architecture, various other system and component changes will be required to implement a “normally closed” system.
Normally-Closed Fuel Tanks

- Sealed fuel tanks can generate pressures in excess of 20 kPa, with vacuum >5 kPa
  - e.g. Toyota relief pressure set at 24 kPa (3.5 psi) for Highlander hybrid
  - High pressure / vacuum combined with typical operating temperatures (>100 degrees C) cannot be achieved using typical plastic fuel tanks
    - Insufficient stiffness leads to excessive volume fluctuation
    - Creep and/or failure at high temperature with high pressure
- Steel can meet all functional requirements through proper wall thickness selection and structural CAE optimization
CAE for Pressure-Vacuum

Fatigue life prediction and design optimization to meet OEM targets
NVH Optimization

- Many hybrids can operate in “all-electric” mode, in which the engine is turned off.
- Engine noise typically creates a noise floor, below which other noises cannot be heard by the passengers.
  - This noise floor is greatly reduced in all-electric mode, creating potential for passengers objecting to previously undetectable noises.
  - Fuel slosh noise can be a major concern for hybrid vehicles.
Slosh Simulation – Effect of Baffles

Reference: I. Ahmad, NESCOM
Slosh Simulation – Effect of Baffles

Fluid Free Surface Visualization

Reference: I. Ahmad, NESCOM
Example of Slosh Baffle
Baffle Integration

• Stamped, welded steel fuel tanks provide inherent opportunities for slosh noise control prior to welding
• Typical blow molding processes make it difficult to integrate slosh control features
  – “Molded-in” baffles decrease fuel capacity
  – Post-molding assembly is difficult and subject to ergonomic and geometric constraints
  – “Ship-in-a-bottle” concepts add cost and manufacturing complexity issues
• Design of baffles can be independent of tank shell design
  – Accommodates engineering changes
  – Easy to include baffles for hybrid models / exclude for non-hybrid
Conclusion

• Steel fuel tanks provide cost-effective, fully recyclable, “zero” emissions solutions for today’s vehicles and market fuels

• Steel provides unique benefits for hybrid vehicles, including plug-in hybrids
  – Inherent ability to meet “zero” emissions
  – Superior strength and stiffness for pressurized applications
  – Enables flexible integration of slosh control baffles
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