Liquefied Hydrogen Carrier Pilot Project in Japan

H2@Port
Wednesday, September 11, 2019
ClassNK
NIPPON KAIJI KYOKAI (ClassNK or NK)

- International classification society in Japan established in 1899
- Abt. 20% share of classification of world cargo vessels in Gross Tonnage
- Head Office: Tokyo, Japan
- Abt. 130 sites in the world for ship survey
- Offices in U.S.: New York, Charleston, Houston, Los Angeles, Miami, New Orleans, Norfolk, Seattle

ClassNK activities relating to hydrogen / fuel cell

- Guidelines providing additional safety requirements for design and construction of the vessels have been issued based on the results of R&D and IMO discussions.
  1. Guidelines for Liquefied Hydrogen Carriers (March 2017)
- Design approval and surveys for construction of LH2C for the pilot project in Japan applying the above Guidelines ①.
LH2 carrier pilot project in Japan

Hydrogen Energy – Demand Growth

“Process gas” ⇒ “FCV” ⇒ “Power generation”

Vast demand for hydrogen

Diffusion of power generation and FCV

Tokyo Olympic/Paralympics As “Hydrogen Olympics”

Fuel Cell Vehicles (FCV) Released

2014 2020 2025

KHI “Introduction to a Liquefied Hydrogen Carrier for a Pilot Hydrogen Energy Supply Chain (HESC) project in Japan”, Gastech 2017
LH2 carrier pilot project in Japan

**Pilot Hydrogen Energy Supply Chain project run by HySTRA***

*) HySTRA: CO2-free Hydrogen energy Supply-chain Technology Research Association composed of Kawasaki Heavy Industries, Shell, Iwatani Corporation, J-Power

*Source: KHI Presentation in SIGTTO Japan Regional Forum 2016*
## LH2 carrier pilot project in Japan

### 1250m³ Liquefied Hydrogen Carrier

![Image of LH2 carrier](image)

**Source:** KHI

<table>
<thead>
<tr>
<th>Liquefied Hydrogen Carrier</th>
<th>LH2 Cargo Containment System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shipyards</strong></td>
<td>Kawasaki Heavy Industries</td>
</tr>
<tr>
<td><strong>Dimensions (Lp x B x D)</strong></td>
<td>ab.110m x ab.20 m x ab.11m</td>
</tr>
<tr>
<td><strong>Gross Tonnage</strong></td>
<td>ab. 8,000 tons</td>
</tr>
<tr>
<td><strong>Propulsion System</strong></td>
<td>Diesel Electric</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>ab. 13.0 knots</td>
</tr>
<tr>
<td><strong>Flag State/Class</strong></td>
<td>Japan / ClassNK</td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Kawasaki Heavy Industries</td>
</tr>
<tr>
<td><strong>Total Capacity</strong></td>
<td>Ab. 1,250 m³ x 1 tank</td>
</tr>
<tr>
<td><strong>Tank Type</strong></td>
<td>IMO Independent tank type C</td>
</tr>
<tr>
<td><strong>Design Press. x Temp.</strong></td>
<td>0.4 MPaG x -253 degC (20K)</td>
</tr>
<tr>
<td><strong>Insulation System</strong></td>
<td>Vacuum Multi-layer Insulation + Supplementary Kawasaki Panel Insulation System</td>
</tr>
<tr>
<td><strong>BOG Management</strong></td>
<td>Pressure Accumulation</td>
</tr>
</tbody>
</table>
Rule requirements for LH2 carrier

IGC Code

Products not listed in Chapter 19
- Hydrogen, etc.

Products listed in Chapter 19
- Methane (LNG), Propane, Butane, Ethylene, etc.

IGC Code 1.1.6.1
Where it is proposed to carry products that may be considered to come within the scope of this Code that are not at present designated in chapter 19, the Administration and the port Administrations involved in such carriage shall establish a Tripartite Agreement based on a provisional assessment and lay down preliminary suitable conditions of carriage based on the principles of the Code.
Rule requirements for LH2 carrier

- Approval to develop Interim recommendations for carriage of liquefied hydrogen in bulk proposed by Australia and Japan
- Start discussion of draft Interim recommendations
- Members: Australia, China, France, Germany, Greece, Japan, Liberia, Marshall Islands, Norway, Korea, Spain, Sweden, UK, USA, ICS, IACS, OCIMF, SIGTTO
- The draft interim recommendations endorsed
- Adoption of IMO Res. MSC.420(97) “INTERIM RECOMMENDATIONS FOR CARRIAGE OF LIQUEFIED HYDROGEN IN BULK”
- Application of the Interim Recommendation to the pilot LH2C was agreed by Australia and Japan
## Table 1: Interim Recommendations for carriage of liquefied hydrogen in bulk

<table>
<thead>
<tr>
<th>Product name</th>
<th>Ship type</th>
<th>Independent tank type C required</th>
<th>Control of vapour space within cargo tanks</th>
<th>Vapour detection</th>
<th>Gauging</th>
<th>Special requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>2G</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Flammable</td>
<td>Closed</td>
</tr>
</tbody>
</table>

See Table 2

## Table 2: Special Requirements carriage of liquefied hydrogen in bulk

(Total 29 Special Requirements)

<table>
<thead>
<tr>
<th>No.</th>
<th>Special Requirement</th>
<th>Related hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>At places where contact with hydrogen is anticipated, suitable materials should be used to prevent any deterioration owing to hydrogen embrittlement, as necessary.</td>
<td>Hydrogen embrittlement (see 4.3)</td>
</tr>
</tbody>
</table>

Ref to IMO Res. MSC.420(97)
Safety Considerations

Design Basis for Pilot LH2C

- IGC Code + Interim Recommendations (IMO Res. MSC.420(97))

- Hydrogen specific standards / guidelines:
  - ISO/TR 15916: Basic Considerations for the Safety of Hydrogen Systems
  - NFPA 2: Hydrogen Technologies Code
  - NFPA 55: Compressed Gases and Cryogenic Fluids Code
  - CGA G 5.4: Standard for Hydrogen Piping Systems At User Locations
  - CGA G 5.5: Hydrogen Vent Systems
  - ASME B31.12-2011: Hydrogen Piping and Pipelines
  - IEC 60078-10-1: Explosive atmospheres - Part 10.1 Classification of areas - Explosive gas atmospheres
  - IEC 60079-29-2: Explosive atmospheres - Part 29.2 Gas detectors - Selection, installation, use and maintenance of detectors for flammable gases and oxygen

- Safety Risk Assessment (HAZID, HAZOP, FMEA, QRA, etc.)
Safety Considerations

Hazards related to Hydrogen

- Low temperature hazard
- Hydrogen embrittlement
- Permeability
- Low density & High diffusivity
- Ignitability

- High pressure hazard
- Health hazard
- Wide range of flammable limits

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen</th>
<th>Methane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling temp (K)</td>
<td>20.3</td>
<td>111.7</td>
</tr>
<tr>
<td></td>
<td>(-253 °C)</td>
<td>(-161.5°C)</td>
</tr>
<tr>
<td>Gas density at standard cod. (273K &amp; 1atm (kg/m³)</td>
<td>0.09</td>
<td>0.72</td>
</tr>
<tr>
<td>Gas density at boiling point (kg/m³)</td>
<td>1.34</td>
<td>1.82</td>
</tr>
<tr>
<td>Liquid density (kg/m³)</td>
<td>70.8</td>
<td>422.5</td>
</tr>
<tr>
<td>Evaporation Latent heat (kJ/L)</td>
<td>31.6</td>
<td>215.8</td>
</tr>
<tr>
<td>Flammability range (% vol)</td>
<td>4 - 75</td>
<td>5 - 17</td>
</tr>
<tr>
<td>Min. Ignition Energy (mJ)</td>
<td>0.017</td>
<td>0.274</td>
</tr>
<tr>
<td>Diffusion Coefficient in air (cm²/s)</td>
<td>0.61</td>
<td>0.16</td>
</tr>
</tbody>
</table>
HAZID study / Accidental Scenario on Hydrogen Leakage

**Threat**

- Permeability
  - Austenite SUS
- Embrittlement
  - Weld joint
- Thermal Contraction
  - Cool-down operation
  - Free movement support

**Mitigative Safeguards**

- Preventive Safeguards
  - Leak test
  - Vacuum gauge
  - Double-wall / Double-shut

**Consequence**

- Top Event: Hydrogen Leakage from Pipes/CCS
  - Water curtain
  - UV flame detector
  - Fire extinguisher system
  - Safety relief valve
  - Gas detector
  - Rapture disc
  - Fire
  - Explosion

*Source: KHI Presentation in SIGTTO Japan Regional Forum 2016*
Safety Considerations

Novel Technologies Qualification

<table>
<thead>
<tr>
<th>Application (Safety Critical System &amp; Equipment)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo containment system</td>
<td>Hazardous area classification</td>
</tr>
<tr>
<td>Vacuum insulated piping</td>
<td>Ship / shore bonding philosophy</td>
</tr>
<tr>
<td>Cargo compressor</td>
<td>Flange management philosophy</td>
</tr>
<tr>
<td>Cargo pumps</td>
<td>Cargo venting philosophy</td>
</tr>
<tr>
<td>Cargo vaporizer / heater</td>
<td>Cargo jettisoning</td>
</tr>
<tr>
<td>Gas Combustion Unit</td>
<td>Cargo hold LIN/LOX protection philosophy</td>
</tr>
<tr>
<td>Level measurement/TPS</td>
<td>Ventilation System</td>
</tr>
<tr>
<td>Relief valves, bellows, gaskets etc.</td>
<td>Gas detection</td>
</tr>
<tr>
<td>Instrumentation (Pressure, Temp., Vacuum press., plugs, sensor)</td>
<td>Fire detection</td>
</tr>
<tr>
<td>Cargo vent mast</td>
<td>Firefighting philosophy</td>
</tr>
<tr>
<td>Cargo manifold</td>
<td>Purging and sampling philosophy</td>
</tr>
<tr>
<td>Marine loading arm &amp; connection piece</td>
<td></td>
</tr>
</tbody>
</table>

Technology Qualified
Verification Experiment

✓ Verification and validation of physical effects modelling software for liquefied hydrogen

Experimental Apparatus

LH2 Vessel (100L)
Discharge Nozzle
Double Wall Pipe

LH2 Leakage from 3.0mm Nozzle

CFD Results

Co-developed with KHI, Iwatani Corporation, K-Line, ClassNK

Source: KHI Presentation in SIGTTO Japan Regional Forum 2016
Safety Considerations

Dispersion Analysis Study

✓ Extended hazardous area in accordance with IEC 60079-10-1

Hazardous area classification

Vent dispersion analysis

Source: KHI Presentation in SIGTTO Japan Regional Forum 2016
Safety Considerations

Airflow Analysis Study

- Improve the airflow within cargo compressor room by optimizing ventilation change rate, inlet/outlet location
- Effective gas detector location

Source: KHI Presentation in SIGTTO Japan Regional Forum 2016
Safety Considerations

ClassNK “Guidelines for Liquefied Hydrogen Carriers”

✓ Guidelines for the design and construction of LH2C
✓ Re-structuring and partly supplementing the interim guidelines with additional requirements

- e.g. Special Requirements in Interim Recommendations: No. 25 “Risk Assessment”

ClassNK Guidelines “Items to be considered in the assessments”
- Predicting venting scenario and safer venting procedures including prevention and mitigation measures for vent fire to explosion and flashback
- Accuracy verification for applied CFD tools to series of dispersion analysis
- Ergonomic evaluation for access routes to LH2 related equipment from safety perspective
- Prevention measures against BLEVE of the CCS
- Influences of small leaked LH2/GH2 in case of ERS activation
- Chain repercussion due to single failure of VMI system for CCS and VIP
- Possibility of negative pressure by Cryo-pumping effect of CCS
- Isolation philosophy and comprehensive hydrogen fire control
- Safety measures in case of blackout of the ship, etc.
Conclusion

- The LH2C for pilot project in Japan has been designed, constructed and operated based on the requirements of IGC Code, Interim Recommendations issued by IMO, relevant hydrogen specific standards / guidelines, and various risk based approach (HAZID, HAZOP, FMEA etc.).

- Safe operation of the pilot LH2C will be verified in trials/tests phase for several months duration after delivery of the ship in 2020.

- The results of these studies would contribute to further development of commercial LH2C and consideration of amendment to IGC code and IGF code to include safety requirements intended for commercial hydrogen carriers and also use of hydrogen as ship fuel.

- ClassNK will update “Guidelines for Hydrogen Carriers” and “Guidelines for Fuel Cell On Board Ships” taking into account both the experience and technical developments.
THANK YOU

for your kind attention