FLNG: operational risks

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FLNG – The FPSO for Gas Operational Risks
Standard Club Offshore Forum – Clive Whitcroft

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Floating Liquefied Natural Gas Vessels (FLNG) Activities

- **Marine Operations**
  - Control of vessel stability & safety etc – *akin to FPSO but extra slopping risk etc*

- **Subsea Operations**
  - Control of wells & receipt of gas – *akin to FPSO*

- **Gas Initial Processing**
  - Gas/liquid separation & gas treatment – *potentially akin to FPSO*

- **Gas Liquefaction**
  - Progressive cryogenic gas liquefaction & separation – *changes from onshore LNG*

- **LNG Storage**
  - Cryogenic storage of LNG at <25kPa (4psi) pressure – *akin to LNG carrier/tanker*

- **LNG Offloading**
  - Discharge into an LNG tanker – *potentially akin to LNG terminal or changes*

- **Floating Storage & Re-gasification Units – FSRU**
  - Proven technology & possibly 10% of global re-gasification by 2015

Natural Gas Composition

- **As Extracted - Methane plus Other Species – Location specific**
  - Some heavier alkanes, eg. Ethane: 0-20%
  - Carbon dioxide: 0-8%
  - Nitrogen: 0-5%
  - Hydrogen sulphide: 0-5%
  - Mercury: Significant traces

- **As Exported – Mainly Methane plus**
  - Some Ethane, to regulate combustion eg. Wobbe index
  - Odorant for leak detection
Natural Gas Properties - 1

- **Liquid**
  - Colourless, odourless, non-toxic, non-corrosive, non-polluting
  - Non-explosive & non-flammable
  - Circa 600 times denser than natural gas & 60% of energy density of diesel
  - Causes cryogenic embrittlement of many materials

- **Vapour**
  - Flammable Limits: Lower (LFL): 5% NG to Upper (UFL): 15% in the air
  - Can be explosive within flammable range
  - Density relative to air: At ambient temp ~ 47%, but just above boiling point ~ 140%
  - Can cause asphyxia

Natural Gas Properties - 2

<table>
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<tr>
<th>Species</th>
<th>Boil °C</th>
<th>Melt °C</th>
<th>Formula</th>
<th>Mol Wt</th>
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<td>- 210</td>
<td>N2</td>
<td>28</td>
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<td>H2O</td>
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</table>
Natural Gas Processing - Typical

- Separation – removal of:
  - Bulk of water, any oil/condensate, mud or sand
- Scrubbing – removal of:
  - Carbon dioxide & H2S, via closed circuit amine wash
- Dehydration – removal of:
  - Water vapour via glycol scrubber & then via molecular sieve (regenerated beds)
  - Mercury via expendable active bed in mol. sieve (to avoid amalgam damage to aluminium plant)
- Refrigeration, Liquefaction & Separation of:
  - Heavier hydrocarbons - alkanes > LPG
  - Nitrogen to 4-5% for gas supply or <1% for LNG, via NRU at −140°C to −180°C
- Treatment of LNG:
  - Adjust ethane level to control combustion
  - Add odorant, eg. a mercaptan

Natural Gas Liquefaction

- LNG History & Basis
  - LNG patent filed in 1914 & first commercial production in 1917
  - Repeated NG compression, cooling with various refrigerants & adiabatic expansion
- Liquefaction – Main Onshore Processes
  - C3MR (Mixed Refrigerant) or APCI – by Air Products & Chemicals
    - Most common with ~86 of ~100 process trains onstream or under construction
  - Cascade – by Conoco Phillips
    - Second most common with ~10 of ~100 process trains
  - Dual Mixed Refrigerant (DMR) – by Shell
    - Only ~3 onshore plants (inc. Sakhalin) – will be used for Shell ‘Prelude’
  - Linde/Statoil
    - Only ~1 plant at Snohvit
- Liquefaction for FLNG – new Nitrogen Based Tricycle – by Technip & Air Products
  - Safer (limited or no C2-C5 refrigerants), small footprint & less motion sensitive
Onshore LNG & NG Accidents - 1

- 1944 – East Ohio Gas LNG Plant, Cleveland, Ohio
  - Brittle fracture of low nickel tank (no bund wall)
  - ~ 1.2M gallons of LNG into sewers, exploded, burnt & killed 128 & 30 acres destroyed

- 1979 – Cove Point LNG Plant, Maryland
  - Pump seal failed, NG into electrical conduit, exploded & killed worker & plant damage

- 2004 – Sonatrach NG Liquefaction Plant, Skikda, Algeria
  - Steam boiler exploded, after ingesting refrigerant hydrocarbon leak
  - Boiler explosion damaged ethane & propane storage, causing major gas explosions
  - 27 killed, 56 injured, 3 LNG trains destroyed, marine berth damaged – cost USD900M

- 2012 Pemex NG Plant in Reynosa, Mexico
  - ‘Sabotage’ initially suspected, then attributed to ruptured pipe/duct near pipeline metering point, but explosion severity not compatible with open nature of plant - TBC
  - 30 killed & 46 injured

- Various Dates & Locations
  - Brittle fracture of carbon steel plating via spills & 2,000t of vapour from rollover in tank

Onshore NG Accidents - 2

2012 Pemex NG Plant – Alternative Views
FLNG
Marine Environment Challenges - Technip

- Mechanical
  - Offloading LNG between two vessels on the high seas
  - Importing large quantities of high pressure feed gas onto a floating facility
  - Equipment and piping loads generated by motion
  - LNG tank sloshing over 25 years without dry docking
  - Maintenance
  - Marine environment – salt & humidity – replace aluminium by stainless & Ni steels

- Process
  - Gas processing facilities to be adapted to marine environment
  - Compact design - weight and volume
  - Designing for motion compared to static onshore plan

- Proposed Liquefaction Development
  - Technip + Air Products: Nitrogen based Tricycle, using coil wound heat exchanger (CWHE) for strength, safety (any leak inside pressure vessel) & performance
LNG Carriers
Storage & Handling Options

• Storage
  • Moss Spherical Tanks
    • Initially 9% nickel-steel, but subsequently 29>57mm thick aluminium
    • Insulated by glass fibre, aluminium foil & expansion foams
    • Overtaken by Membrane, but use for SBM double tanker FLNG with Linde train
  • Membrane Tanks
    • No. 96: Dual layer 0.7mm Invar (36% Ni steel) in plywood boxes filled with perlite
    • Mark III: 1.2mm low temp. stainless + fibreglass reinforced polyurethane foam with Triplex plastic secondary barrier
  • Temperature Control
    • Latent heat absorption from low boil-off rates (~0.15%>0.10%/day) maintains LNG temperature
    • Boil-off gas either burnt to generate power &/or steam or re-liquefied (newer vessels)

FLNG Storage & Handling Options - 1

• Storage Challenge – with part filled tanks
  • Reducing sloshing & impact on stability & tank & insulation integrity for 20+ years
• Storage Tank Options
  • Self supporting prismatic, eg. Daewoo Aluminium Cargo Tank Independent Type B
  • Two-row membrane tanks, either side of central cofferdam, eg. by Höegh LNG
  • ‘Prelude’ will have 6 LNG & 2 LPG tanks – type TBA
• Temperature Control
  • As per carriers/tankers
• Offloading
  • Mechanical arms (‘Prelude’: 4*LNG & 3*LPG): parallel offloading (‘Prelude’ conclude insignificant spill risk, due to double hulls, fenders, tugs, thrusters, weather limits etc
  • Cryogenic hoses: tandem offloading – increase vessel separation & weather window
FLNG
Storage & Handling Options - 2

Concept: Dual floating cryogenic LNG offloading hoses & dual cryogenic boil-off return hoses

DNV has qualified Technip hose for Amplitude LNG Loading System (ALLS) at GdF site

Also Trelleborg-Saipem offshore development

Platforms, FPSO & FLNG
Hazard Factors - Plant, Process & People

• Layout & Arrangements
  • Failure to locate by risk & consequence
  • Inadequate protective barriers, evacuation & rescue systems
  • Congestion & lack of venting & pressure relief facilities

• Mechanical
  • Risk level of process selected
  • Inadequate component strength
  • Material degradation failures in service or brittle fracture during LNG spillage
  • Connection leaks – process plant or offloading

• Control
  • Electrical & electronic system failures – initial & response
  • Procedure & communication system deficiencies
  • Operator errors – initial & response

• External
  • Vessel impacts
  • Terrorist action

• *Piper Alpha* – many above applied & 165 died > Safety Cases & integrated approach
### Plant & Process Hazard Results - 1

**Hydrocarbon (HC) Escape**

- **UVCE: Uncontained Vapour Cloud Explosion**
  - In open spaces if obstructions/congestion create enough turbulence for flame front speed to generate sufficient pressure (*pressure increases with square of speed*)
  - Caused major damage at Flixborough & Buncefield etc with other HC – see later
  - DNV et al consider NG UVCE not feasible over open water, due to low flame front speed & condensed fog in the gas cloud

- **BLEVE: Boiling Liquid Expanding Vapour Explosion**
  - In confined spaces, eg. tanks & vessels, leading to rupture & container etc destruction
  - Need external heat to generate vapour & influenced by fluid level & relief valves etc
  - Can occur without combustion, eg. with water

- **RPT: Rapid Phase Transformation**
  - Cold explosion via rapid liquid to vapour phase change, eg. LNG into water or reverse
  - Potential local structural damage to hull & equipment

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### Plant & Process Hazard Results - 2: GL-ND Spadeadam Tests

- **Pool Fire – Kerosene**
- **NG Leak Fire – Valve spindle leak leak at 30barg**
- **Pool Jet Fire – NG leak from 20mm hole at 70barg**
- **NG Vapour Cloud Explosion - Deflagration**
- **Venting of NG Explosion**
Plant & Process
Combustion & Explosion Mechanisms

- **Deflagration – feasible with NG**
  - **Subsonic** flame propagation (<100m/s vs ~300m/s) & low overpressure (eg. <0.5 bar)
  - Combustion propagates as flame front moves forward through the gas mixture
  - Requires some congestion to be sustained (eg. pipework or trees)
  - Partial confinement & many obstacles can cause turbulent flow & eddies, which may accelerate flame from subsonic to supersonic & change deflagration to detonation

- **Detonation – requires containment or long flame path with NG**
  - **Supersonic** flame propagation (up to 2,000m/s) & **high overpressure** (up to 20 bar)
  - Pressure shock wave compresses unburnt gas ahead of wave to temperature above auto-ignition temperature & detonation occurs
  - Effects of a detonation are usually devastating

- **Deflagration to Detonation Transition (DDT) – features in major losses inc:**
  - 1974 cyclohexane VCE from pipe rupture in Flixborough chemical plant
  - 1989 propane rich VCE from leaking pipeline in Russia
  - 2005 oil spillage VCE at Buncefield Oil Storage Terminal

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LNG Carriers & FLNG
Hazard Mechanism - RPT

Rapid Phase Transformation – **Modelling by ioMosaic**

- **Large hole above water & tank 98% full**
  - LNG discharge onto water
  - RPT near outside of hull & pool forms

- **Large hole below water & tank 98% full**
  - Initially LNG discharges into water
  - RPT near outside of hull & pool forms
  - Then some water into tank

- **Large hole just below water but tank 25% full**
  - Water enters tank & mix with LNG
  - RPT inside tank & possibly severe tank damage
  - Water freezes in tank, after heating LNG

- **The hazard potential of RPT is very localised, but might be severe**
- **RPT more likely if LNG contains ethane & propane**
Plant & Process
Significant Hazard Investigations

- Practical Tests
  - Fire & explosion tests by BG/GL-Noble Denton at Spadeadam:
    - Explosion severity increases from methane to propane, ethane & ethylene
    - LPG extraction & refrigeration may introduce up to ~ 70% of FLNG process risk
  - LNG onto water tests by GdF, Shell Maplin Sands & Lawrence Livermore in USA

- Computational Fluid Dynamics
  - GexCon ‘FLACS’ – Flame Acceleration Software used to model plant design & major incidents, inc. Piper Alpha & Petrobras 36 platforms & Buncefield
  - DNV ‘PHAST’ modelling of onshore & on water LNG leaks & fires, inc. flammable atmosphere distances (if no ignition) for different hole sizes above & below water line, eg. ~900m for 750mm hole above water line or up to ~3km for 1500mm terrorist hole

LNG Carriers & FLNG
Hazard Assessment – Chevron 2002

- LNG carrier incidents:
  - 8 spillage incidents – some brittle fracture hull damage
  - No cargo fires or explosions
  - 2 grounding incidents – no significant loss of cargo
  - LNG carriers more robust than tankers

- LNG pools on water:
  - No BLEVE – only occur with combustible mixtures in confined spaces
  - Can undergo RPT or form pool which burns or evaporates faster than on land
  - Cloud warms, rises & if ignited, burns until all burnt or concentration below LFL - can burn (subsonic) back to leak source, via residual spill pool
  - LFL modelled from 0.5 to 2.5 miles & burn times from 64 to 37 minutes for 25km² spill via 1m & 5m holes - multiple ignitions likely from larger terrorist holes

- NB: Addresses LNG Carriers & Spills on Water, but not FLNG Liquefaction train etc
FLNG Hazard Avoidance - Layout

'Prelude'

SBM Concepts