Eksplosjonsrisiko, værbeskyttelse og optimalisering av design

HMS utfordringer i Nordområdene – Arbeidsseminar 4

Asmund Huser
20 May 2014
Content

- Challenges and Objectives
- Explosion risk analysis as decision making tool
  - Explosion theory
  - Example FPSO in arctic
- Wind chill and outdoor operations
  - Theory and principles
- Typical scope ERA and Wind Chill Analysis
- Optimization of design
  - Improving ventilation with passive and active systems
  - Mitigating explosions
- Summary and recommendations
Main safety challenges in arctic

- Ensure safe design wrt process safety and working environment
- Objectives:
  - Give recommendations and decision support in order to optimize working environment AND safety
  - Comply with regulations
Explosion risk analysis as decision making tool
Overall risk analysis and risk based design procedure

- Break down and organize consequences and frequencies – Examination
- Simulate all events – Risk Analysis

- Point at risk drivers – Diagnosis
- Deliver design improvements
- Find solutions together with contractor

Diagram:
- Start
- Establish Scenarios
- Consequences CFD
- Frequencies LEAK
- Mitigate
- Risk assessment e.g. EXPRESS
- Escalation?
- Yes
- No
- Stop
Explosion Risk Analysis approach

EXPLOSION ANALYSIS:
- Geometry modeling
- Ventilation
- Dispersion
- Explosion

Probabilistic analysis:
- DNV program EXPRESS
- Response surfaces
- JIP Ignition model
- Monte Carlo simulations

Design effects and recommendations
Explosion Design Accidental Loads
Pressure frequency exceedance curves
Ignition probabilities

Sensitivities?
Large semi-sub
Gas leak starts, $t = 0$ s
Gas leak dispersion simulation, $t = 5\ s$
Gas leak dispersion simulation, $t = 10\, \text{s}$
Gas leak dispersion simulation, $t = 15$ s

Wind direction

Leak location

Top view

Side view

Below LEL

Above UEL
Gas leak dispersion simulation, $t = 20$ s
Gas leak dispersion simulation, $t = 25$ s
Gas leak dispersion simulation, $t = 30$ s

- **Wind direction**
- **Leak location**

**Top view**

- **Above UEL**
- **Below LEL**

**Side view**
Gas leak dispersion simulation, $t = 35 \text{ s}$
Gas leak dispersion simulation, $t = 40$ s

- **Wind direction**
- **Leak location**

**Above UEL**

**Below LEL**

**Top view**

**Side view**
Gas leak dispersion simulation, $t = 45 \text{ s}$

- **Wind direction**
- **Leak location**
- **Top view**
- **Side view**
- **Below LEL**
- **Above UEL**
Gas leak dispersion simulation, $t = 50$ s
Gas leak dispersion simulation, $t = 55$ s
Gas leak dispersion simulation, $t = 60$ s
Gas leak dispersion simulation, $t = 65$ s

Wind direction

Leak location

Above UEL

Below LEL

Top view

Side view
Gas leak dispersion simulation, $t = 70\,\text{s}$

- **Above UEL**
- **Below LEL**

**Wind direction**

**Leak location**

**Top view**

**Side view**

**Below LEL**
Gas leak dispersion simulation, $t = 75$ s

- **Wind direction**
- **Leak location**

**Above UEL**

**Below LEL**

**Top view**

**Side view**
Gas leak dispersion simulation, $t = 80$ s

Wind direction

Leak location

Above UEL

Below LEL

Top view

Side view
Gas leak dispersion simulation, $t = 85$ s

Wind direction

Leak location

Above UEL

Below LEL

Top view

Side view
Gas leak dispersion simulation, $t = 90\ s$

Top view

Wind direction

Leak location

Above UEL

Below LEL

Side view
Gas leak dispersion simulation, \( t = 95 \) s

- **Wind direction**
- **Leak location**
- **Top view**
- **Side view**
- **Above UEL**
- **Below LEL**
Gas leak dispersion simulation, $t = 100$ s
Gas leak dispersion simulation, $t = 105$ s

Wind direction

Leak location

Above UEL

Below LEL

Top view

Side view
Gas leak dispersion simulation, $t = 110 \text{ s}$

2

Wind direction

Leak ends

Above UEL

Below LEL

Top view

Side view

Below LEL
Gas leak dispersion simulation, $t = 115$ s
Gas leak dispersion simulation, $t = 120$ s

- Top view
- Side view
- Below LEL
- Above UEL

Wind direction
Gas leak dispersion simulation, $t = 125$ s
Explosion pressure wave starts, $t = 0$ s

Ignition

Top view

Side view

Above 0.5 barg

0 barg
Explosion pressure wave starts. $t = 1.15\, \text{s}$

- Top view
- Side view
- Above 0.5 barg
- Below 0.0 barg
Explosion pressure wave, $t = 1.2$ s

Above 0.5 barg

0 barg
Explosion pressure wave, $t = 1.22$ s
Explosion pressure wave, $t = 1.23\ s$
Explosion pressure wave, $t = 1.24$ s
Explosion pressure wave, $t = 1.25$ s

Above 0.5 barg

0 barg
Explosion pressure wave, $t = 1.253$ s

Above 0.5 barg

Side view

Top view

Below 0.02
Explosion pressure wave, $t = 1.26$ s
Explosion pressure wave, $t = 1.27 \text{ s}$
Explosion pressure wave, $t = 1.28$ s
Explosion pressure wave, $t = 1.29$ s
Explosion pressure wave, $t = 1.295\ s$
Explosion pressure wave, $t = 1.3$ s
Explosion pressure wave, $t = 1.32$ s
Physics highlights

- Ventilation should be good before leak starts to dilute the gas
- Gas cloud develops fast, within 30-60 s for large leaks.
  - Light gas collects under roofs
  - Heavy gas spreads along deck
- Explosion starts slow and then ... boom!
  - Effects that decides when it takes off and how high it gets:
    - Size (distance) of combustible gas cloud
    - Congestion
    - Confinement
Example FPSO in arctic

- Turret moored FPSO
- Winterized process area
15 deg wind heading
Wind speed inside process area, 15 deg heading
Velocity vectors, 15 deg heading
Velocity vectors transverse planne, 15 deg heading
Example dispersion simulations. Gas under roof – light gas
Example dispersion simulations. Gas under roof
Applied designs that prevents and mitigates explosions

- Preventive effects are preferred over mitigating effects
  - Reduces both explosion and fire risk
- Focus on improving ventilation and dispersion
  - Inherent safe design
  - Active ventilation control
    - Active weather panels
    - Platform orientation
Wind Chill and Outdoor Operations
Theory and principles
Theory and Principles - Cold Challenges

- Cold stress factors
  - Wind
  - Precipitation and moisture
  - Low temperatures
  - Direct exposure to cold surfaces
  - Activity
  - Work clothing

- Wind chill and outdoor operations
  - Wind chill temperature (°C)
    
    \[
    t_{WC} = 13.12 + 0.6215 \cdot v_3 - 11.37 \cdot T_{10}^{0.16} + 0.3965 \cdot v_3 T_{10}^{0.16}
    \]

  - Effective Heat Loss per time, WCI (W/m²) (ISO/TR 11079)
    
    \[
    I_{WC} = 1.16 \left( 10.45 + 10u^2 - u \right) (33 - T)
    \]
Effective temperatures considering wind chill

Effective temperature as function of wind and ambient temperature

<table>
<thead>
<tr>
<th>Vind (km/t)</th>
<th>5</th>
<th>0</th>
<th>-5</th>
<th>-10</th>
<th>-15</th>
<th>-20</th>
<th>-25</th>
<th>-30</th>
<th>-35</th>
<th>-40</th>
<th>-45</th>
<th>-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flau vind</td>
<td>4</td>
<td>-2</td>
<td>-7</td>
<td>-13</td>
<td>-19</td>
<td>-24</td>
<td>-30</td>
<td>-36</td>
<td>-41</td>
<td>-47</td>
<td>-53</td>
<td>-58</td>
</tr>
<tr>
<td>Lett bris</td>
<td>2</td>
<td>-4</td>
<td>-11</td>
<td>-17</td>
<td>-23</td>
<td>-29</td>
<td>-35</td>
<td>-41</td>
<td>-48</td>
<td>-54</td>
<td>-60</td>
<td>-66</td>
</tr>
<tr>
<td>Laber bris</td>
<td>1</td>
<td>-6</td>
<td>-12</td>
<td>-19</td>
<td>-25</td>
<td>-32</td>
<td>-38</td>
<td>-44</td>
<td>-51</td>
<td>-57</td>
<td>-64</td>
<td>-70</td>
</tr>
<tr>
<td>Liten kuling</td>
<td>-1</td>
<td>-7</td>
<td>-14</td>
<td>-21</td>
<td>-27</td>
<td>-33</td>
<td>-40</td>
<td>-47</td>
<td>-53</td>
<td>-60</td>
<td>-66</td>
<td>-73</td>
</tr>
<tr>
<td>Sterk kuling</td>
<td>-2</td>
<td>-9</td>
<td>-16</td>
<td>-23</td>
<td>-30</td>
<td>-36</td>
<td>-43</td>
<td>-50</td>
<td>-57</td>
<td>-64</td>
<td>-71</td>
<td>-78</td>
</tr>
<tr>
<td>Liten storm</td>
<td>-3</td>
<td>-10</td>
<td>-17</td>
<td>-24</td>
<td>-31</td>
<td>-38</td>
<td>-45</td>
<td>-52</td>
<td>-59</td>
<td>-66</td>
<td>-73</td>
<td>-80</td>
</tr>
</tbody>
</table>

Uncomfortably cold
Very cold, risk for frost bites
Risk for skin frost damage after 10 min
Risk for skin frost damage after 2 min
NORSOK and US limitations

NORSOK vs US NWS limitations chart.
Effective Heat Loss per time (ISO/TR 11079 - NORSOK S-002, 2004 reference)

\[ I_{WC} = 1.16 \left( 10.45 + 10u^2 - u \right) \left( 33 - T \right) \]
Other influences

- Night work – increased heat loss
- Age – Lowered tolerance
- Sex – Men tolerate cold better
- Ethnical differences – Polars benefit
- Medical conditions – heart, Reynaud (likfingre)
- Work intervals
Optimal design related to weather protection

- Wind walls and enclosures to provide weather protection

Potential explosion risks due to confinement and enclosures:
- Gas cloud build-up
- No explosion relief

Balancing Process safety vs Working environment

Requirements:
- NORSOK S-002, Section 4.4.9/5.8
- NORSOK S-001, Section 15.4.1

Practice:
- NORSOK Z013 annex F
ERA and ACH Assessment

Obtain DAL pressures from ERA. Assess if DAL is acceptable
- NORSOK Z013 Annex F is followed
- Use same geometry model for WCI sims
Assess if minimum required ventilation rate is obtained
- Assess NORSOK S001 criteria of minimum 12 ACH 95% of the time
  - ACH exceedance curve found by combining wind rose with ventilation simulation results
  - The upper 95% ACH percentile read off the curve
WCI distribution calculations: Unavailability

WCI distribution for work areas calculated and assessed towards criteria

- Unavailability calculations considering
  - Distribution of WCI levels
  - Availability per WCI level
  - Work area distribution

- Criteria:
  - Yearly unavailability < 2%
Outdoor Operation and safety Workshop

Identification, discussion and measures
- Different disciplines including operational personnel attending
- Use ERA and WCI assessment to point at:
  - explosion risk drivers and
  - Challenging work areas wrt wind
- Identify improvement measures
- Find solutions that works and is possible
  - Design
  - Operation
- Further work
Reference Documents and Standards

- **Relevant standards**
  - NORSOK S-002 Working Environment, Rev. 4, August 2004
  - NORSOK S-001 Technical Safety, Rev. 4, February 2008
  - NORSOK Z013 Annex F Procedure for Probabilistic Explosion Simulations 2010
  - ISO 11079:2007. Ergonomics of the thermal environment - Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects, Edition 1, December 2007

- **Reference Reports**
  - Health Aspects of Work in Extreme climates, A guide for oil and gas industry managers and supervisors. OGP Report Number 398, 2008
Applied designs that reduce explosions and improve working areas

- Preventive effects are preferred over mitigating effects
  - Reduces both explosion and fire risk
- Focus on improving ventilation and dispersion
  - Inherent safe and work place friendly design
  - Active ventilation control
    - Active weather panels
    - Platform orientation

Prevent by:
- Ventilation
- Dispersion
- Plus avoid high wind

Mitigate by:
- Venting
- Explosion reduction
- Fire reduction

ignition
Prevention by inherent safe ventilation design

- Main air comes in through wall openings and in arctic the openings are reduced significantly
  - Optimize WCI vs. dispersion
  - Open as much as possible without breaching WCI requirements
- Avoid gas accumulation under roof
  - More openings high up on the walls
  - Roof openings
Openings along upper parts
**Roof design**

- Important to get the gas out quickly
  - Permanent openings best
- Snow and ice challenge
  - Causes build-up of weight which stops explosion release panels
  - Snow can come into the process
  - Separate snow simulations can be performed
  - Heat tracing becomes very extensive
Prevention by inherent safe ventilation design

- Avoid re-circulation flow in process areas
  - FPSO Safety gaps show benefits
  - Blast walls upwind gives re-circulation and poor ventilation

- Limit size of explosion areas
  - Process areas, use plated decks between modules
  - FPSO, use plated 1st process deck

- Minimize blocking by equipment of module air inlets
Prevention by active ventilation control

- Active weather panels in walls
  - Opens when gas is detected
  - Opens when temperature is higher
  - Opens when areas are unmanned
  - New technology – ice and snow challenge
- Roof panels
  - Can open when temperature is higher
  - Snow and ice challenge
- Ventilated and heated rooms where most of work is performed
  - Challenge with leak sources inside
- FPSO active thrusters to improve ventilation
- Fans to improve ventilation: last resort
  - Requires large fans
  - Represent ignition source
Mitigation of explosions

- Congested equipment and piping away from walls and decks
- Avoid corners in walls
- Reduce congestion by more space
- Minimize blocking of module venting openings
- Use explosion panels in walls and ceilings
Preventive and/or mitigating measures

- **Process:**
  - Smaller segments
  - Automatic blowdown
  - Quick ESD valves
  - Shutdown of ignition sources
  - Good gas detection

- **Fire protection**
  - Optimize blowdown vs PFP
  - Use quick blowdown instead of PFP
  - Internal escape route
  - Avoid trapping of smoke by large items
Arctic weather protection options

- Passive Windwalls typically used in the North Sea
  - Wind cladding
  - Porous windwalls
  - Louvres
  - Explosion release panels

- Active weather panels

- Roof design
Active Panel Geometry

- Part of wall has AWP
- Total opening degree is important
- Combination of open, closed and AWP
How AWP can operate / different strategies

- Open on gas detection
  - Often too late to reduce gas cloud
- Automatic operated based on wind and temperature, snow and ice:
  - Open at good weather
  - Close when people are present and weather is bad
Recommendations – Wall designs

- **Additional Ventilation where required**
  - Higher levels where buoyant release accumulates
  - Alteration to roof opening design to allow more gas to escape
  - Not frequently manned areas

- **More Control where required**
  - Active weather panels positioned at working heights on lower and upper deck
  - Allows control of wind speed where people will be working
  - Automatic opening during low wind speeds and high temperatures

- **Pop Out blast panels**
  - Can significantly reduce explosion pressures
LQ, helideck, utility and process location on FPSO

- LQ and helideck upwind to avoid
  - Smoke
  - Exhaust
  - Turbulence
  - Gives poor ventilation to process

- LQ and Helideck downwind
  - Gives better ventilation to process modules
  - Must ensure long enough distance from process to LQ
  - Conflicts with aft offloading
SUMMARY AND RECOMMENDATIONS
Recommended measures

- Layout and process recommendations
- Personal protective wear and equipment
- Temporary windbreaks or active wind walls
- Procedures and operation – Work restrictions, “Cold permit”
- Information, coursing and medical preparedness
- Access to heated shelters close to cold working areas
Benefits of combined explosion and wind chill analyses

- Wind chill and explosion challenges identified in early project phase, and not later based on “bad” experiences
- Difficult or costly to implement improvement measures after early design phases
- Decision support for a safe and sustainable design and operation
Thank you!

Asmund.huser@dnvgl.com
+47 91730337

www.dnvgl.com

SAFER, SMARTER, GREENER