Carbon Monoxide Hazards from Perforating During Plug and Abandonment Operations

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Incident Background

- North Sea, June 2016
- Routine plug and abandonment (P&A) operation
- Explosive perforation followed by rapid circulation to prepare wellbore and annulus for plugging
- Gas detectors on the platform indicated a high concentration of carbon monoxide (CO) was present
- Action was taken to remove personnel from the exposure area
- Perforation operation was identified as the only feasible source for CO

What made this perforation operation different that caused a CO hazard?
Hazards of CO

- CO is a colorless and odorless gas
- CO binds to red blood cells, preventing oxygen transport
- Over-exposure can lead to asphyxiation and death

- In 1994, three workers were killed by CO poisoning after perforating operations at Seacliff well in Ventura County, California
- A risk assessment report by Research Triangle Institute discusses this incident and perforating operations in general

CO hazards of perforating were investigated at least as early as 2000
Origin of CO in Perforating

• CO is normally associated with incomplete combustion

• The detonation of explosives creates CO as a fundamental part of the chemical reaction (e.g., HMX):

CO is a normal by-product of explosive detonation and perforating
Quantity of CO Generated

- Generally, explosives with higher thermal stability contain less oxygen and produce more CO.
- The table shows example volumes of CO generated for a 180-ft interval at 18 shots per foot (126 kg NEC):

<table>
<thead>
<tr>
<th>Explosive Type</th>
<th>Carbon Monoxide Generated (volume at surface)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cubic meters</td>
</tr>
<tr>
<td>RDX</td>
<td>20.4</td>
</tr>
<tr>
<td>HMX</td>
<td>17.5</td>
</tr>
<tr>
<td>HNS</td>
<td>33.0</td>
</tr>
<tr>
<td>PYX</td>
<td>31.3</td>
</tr>
</tbody>
</table>

Significant quantities of CO can be generated during perforation.
Mitigation of CO in the perforating guns:

- Adding an oxidizer (e.g., perchlorate) inside the gun system is calculated to reduce CO a maximum of 25%
- Energy released in the gun increased by 8%
- Therefore, the following occurred
  - Insignificant reduction of CO risk
  - Increased risk of gun rupture
- Introducing other materials in the gun to reduce costs (e.g., cardboard charge tube) can increase CO production

Mitigation of CO production in the perforating gun is not a complete solution
Mitigation of CO in the wellbore:

- Under wellbore conditions, CO is a relatively stable gas
- It is largely nonsoluble in aqueous or organic fluids
- It has the potential to form highly toxic metal-carbonyl compounds
  - Fe(CO)$_5$, Ni(CO)$_4$, Cr(CO)$_6$
- The feasibility of reducing CO risks in the wellbore using an introduced chemical is not known

Mitigation of CO gas in the wellbore is not feasible
Mitigation of CO at the surface:

• Normally, during perforating, observing detonation gases at the surface might not occur and is difficult to predict
• During P&A operations, the timeframe for gas release can be short because of shallow depths and high circulation rates
• This combination increases the likelihood and risk of CO exposure
• The removal of gas separation/handling equipment before P&A operations hampers engineering controls of detonation gases

P&A operating conditions can present an increased CO hazard
Mitigation of CO at the Surface

- Gas separation equipment needs to be available to isolate and control the detonation gases at the surface
- Never vent detonation gases into a confined area
- Place vent openings as far above the surface as feasible
- Control the rate of release to reduce localized concentrations
- CO is less dense than air and will dissipate
- Ensure compliance with applicable HSE regulations

Controlled venting above surface level is the simplest CO mitigation method
Mitigation of CO at the Surface (Cont)

If controlled venting of CO is not allowable:

- Convert CO to CO$_2$ by means of combustion through an operational flare unit

CO can be readily combusted to form relatively benign CO$_2$
Mitigation of CO at the Surface (Cont)

If controlled venting of CO is not allowable:

• Scrub CO from the gas stream by means of catalytic conversion at room temperature to CO$_2$ using a portable system$^1$
• This process requires the following:
  • Careful gas pressure control
  • Controlled mixing with air for reaction
  • Monitoring of catalyst life
  • Outside venting of remaining gases

CO can be catalytically converted to CO$_2$, but this is a more complicated method
Conclusions

- Any time explosives are detonated, CO gas is produced
- P&A operations can exacerbate the risk of CO exposure through unintended processes and lack of engineering controls
- Methods are available to help mitigate CO exposure risks
- Process safety management (PSM) and management of change (MOC) should be used to help ensure robust risk mitigation

CO exposure risks during P&A operations can be managed
Thank you!

Questions?

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