Carbon Monoxide Hazards from Perforating During Plug and Abandonment Operations
Outline

- Incident background
- Hazard description
- Mitigation options
- Conclusions

Reference:

SPE-187036-MS
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):

\[ \text{CO is a normal by-product of explosive detonation and perforating} \]

\[ 1 \, \text{C}_4\text{H}_8\text{N}_8\text{O}_{8s} \rightarrow 4 \, \text{N}_2(g) + 4 \, \text{H}_2\text{O}(g) + 1 \, \text{CO}_2(g) + 2 \, \text{CO}_g + 1 \, \text{C}_s \]
Quantity of CO Generated

- Generally, explosives with higher thermal stability contain less oxygen and produce more CO.

- This 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>RDX</td>
<td>cubic meters</td>
</tr>
<tr>
<td></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.
The CO Life Cycle During P&A

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 increases by 8%
- Therefore, this mitigation technique would bring:
  - 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
Under wellbore conditions, CO is a relatively stable gas. It is largely non-soluble 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.
The CO Life Cycle During P&A (Continued)

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 (Continued)

If controlled venting of CO is not allowable:

- Convert CO to CO2 by means of combustion through an operational flare unit

CO can be readily combusted to form relatively benign CO2
Mitigation of CO at the Surface (Continued)

If controlled venting of CO is not allowable:

- Scrub CO from the gas stream by means of catalytic conversion at room temperature to CO2 using a portable system¹
- This process requires the following:
  - Careful gas pressure control
  - Controlled mixing with air for reaction
  - Monitoring of catalyst life
  - Outside venting of remaining gases

¹ Available from Western Safety Products
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.

CO hazards and mitigation are being addressed in the API RP67 (3rd edition).
Relevant to Asia Pacific?

Fig. 1—The majority of facilities in the Asia Pacific region are at least 20 years old.
Source: Decision Strategies.

Offshore decommissioning in Asia Pacific could cost US$100 billion
Four levers identified to cut cost significantly
01 February 2016

According to Wood Mackenzie’s latest analysis, decommissioning Asia Pacific’s offshore assets – nearly 2,600 platforms and 35,000 wells – could cost over US$100 billion.

Malaysia Gears Up of the Decommissioning and Mature Wells Management Conference

PETRONAS, Pertamina and Talisman Malaysia are all sharing their development of decommissioning strategies at the event.

CO Hazards from Perforating during Plug and Abandon Operations
QUESTIONS?
THANK YOU!