Risk Assessments for Releases from Highly Volatile Liquid Pipelines

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Pipeline operators are required by code (49 CFR Part 195.452) to have a process in place for identifying pipeline segments that could affect a high consequence area (HCA).

In addition to having the HCAs identified, pipeline operators must take special measures to protect these areas and mitigate the associated risks.

Depending on the type of product being transported, a product release could result in liquid plumes, vapor dispersion, or a combination of both; which the operators need to account for in their processes.
Overview

- What is a High Consequence Area?
- What are Highly Volatile Liquids (HVLs)?
- Modeling of Releases of HVLs
- HCA Analysis for HVL Pipelines
- Mitigating Risk through Emergency Flow Restriction Device (EFRD) Analysis
What is a High Consequence Area?

High Consequence Areas (HCAs) include:

- High Population Areas
- Other Populated Areas
- Commercially Navigable Waterways
- Unusually Sensitive Areas

Two types of High Consequence Areas (HCAs)
- Direct
- Indirect
HCA Could Affect Criteria

- Factors that contribute to creating indirect HCA segments on a pipeline

- Operating Conditions
- Terrain
- Potential Release Volume
- Pathways of released liquid
- Response Capability
- Product Characteristics

HCA Could Affect Determination
What are Highly Volatile Liquids (HVLs)

- Liquids when stored at a certain temperature or pressure
- Can quickly vaporize when released to atmospheric conditions
- Common HVLs transported in pipelines include:
  - Natural Gas Liquids
    - Ethane, propane, butane, Isobutane, Pentanes
  - Ethylene
  - Propylene
  - Anhydrous ammonia
HVL Releases

Wind

Vapor Cloud

Droplets/Mist

Evaporation

http://www.trcsolutions.com/
HVL Implications for HCA Analysis

- Requires determining impacted HCAs by considering:
  - Vapor cloud dispersion and concentrations
  - Liquid pooling and potential plume pathway
  - Evaporation from liquid plume

- How is this determined?
  - Atmospheric dispersion modeling
  - Liquid spill plume modeling
Modeling of Releases of HVLs

- **Step 1 – Analysis of HVL Composition**
- **Step 2 – Release Calculation**
- **Step 3 – Atmospheric dispersion modeling**
- **Step 4 – Liquid plume modeling**
- **Step 5 – Evaporation from liquid plumes**
Most HVL products are composed of multiple chemicals, in varying quantities.

- Y-Grade NGL:
  - Ethane: 34%
  - Propane: 10%
  - Butane: 4%
  - Isobutane: 5%
  - Pentanes: 2%
  - Methane: 1%
  - Ethane: 44%
  - Propane: 5%
  - Butane: 2%
  - Isobutane: 1%
  - Pentanes: 1%
  - Methane: 2%

- Butane:
  - Butane: 5%
  - Propane: 2%
  - Isobutane: 4%
  - Pentanes: 3%

- Ethane:
  - Ethane: 44%
  - Propane: 5%
  - Methane: 1%
Analysis of HVL Composition

- Each chemical has different physical properties and will behave differently in the event of a release
- Most models don’t handle these mixtures
- The conservative approach is to model each chemical individually:
  - Perform release calculations on each chemical individually
  - Scale release calculations by overall composition
  - Simulate releases of each chemical individually
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Release Calculation

- Releases can pass through multiple stages:
  - Liquid release, Boil-off, Over pressurization, Depressurization
- At each phase the released chemical can exist in one or many states:
  - Liquid, vapor, droplets/mist
- Release rates will vary over time, and through different stages of the release
- Release rate tapers off to zero once pipeline reaches atmospheric pressure.
Release Calculation

![Graph showing Ethane Release Rate over time with different release conditions: Boil-off (100% Vapor), Overpressurization (33% Droplets/Mist, 67% Vapor), and Depressurization (100% Vapor).]

http://www.trcsolutions.com/
Release Calculation

Butane Release Rate

- **Overpressurization**
  - 50% Droplets/Mist
  - 50% Vapor

- **Liquid Release**
  - 25% Vapor
  - 50% Droplets/Mist
  - 25% Liquid

- **Depressurization**
  - 100% Vapor

Release Rate (kg/s)

Time (seconds)
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Atmospheric Dispersion Modeling

- Used to determine the spatial extent of the vapor cloud and vapor concentrations from the ruptured pipeline
- Inputs to the modeling:
  - Chemical Properties
  - Release Rate and Duration
  - Environmental Conditions

- Outputs from the modeling:
  - Vapor plume dimensions (width, height)
  - Instantaneous & Time Averaged Concentrations
  - Maximum distance to specific concentration threshold
Thresholds of Concern

- Lower Explosive Limit (LEL)
  - Concentration threshold at which the vapor could catch fire if there were an ignition source

- Health Risk Thresholds
  - Concentrations exceeding these for a defined time period can cause toxic effects
    - Level 1 – reversible effects (discomfort, irritation, etc.)
    - Level 2 – irreversible effects, long-lasting effects, impaired ability to escape
    - Level 3 – life-threatening effects or death
  - Sources of thresholds
    - Acute Exposure Guideline Levels (AEGLs) - EPA
    - Temporary Emergency Exposure Limit (TEEL) - DOE
## Concentration Thresholds (ppm)

<table>
<thead>
<tr>
<th>Threshold</th>
<th>LEL</th>
<th>Level-1</th>
<th>Level-2</th>
<th>Level-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Period</td>
<td>Instantaneous</td>
<td>60 minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>50,000</td>
<td>65,000</td>
<td>230,000</td>
<td>400,000</td>
</tr>
<tr>
<td>Ethane</td>
<td>29,000</td>
<td>65,000</td>
<td>230,000</td>
<td>400,000</td>
</tr>
<tr>
<td>Propane</td>
<td>21,000</td>
<td>5,500</td>
<td>17,000</td>
<td>33,000</td>
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<tr>
<td>n-Butane</td>
<td>19,000</td>
<td>5,500</td>
<td>17,000</td>
<td>53,000</td>
</tr>
<tr>
<td>IsoButane</td>
<td>18,000</td>
<td>5,500</td>
<td>17,000</td>
<td>53,000</td>
</tr>
<tr>
<td>n-Pentane</td>
<td>15,000</td>
<td>3,000</td>
<td>33,000</td>
<td>200,000</td>
</tr>
<tr>
<td>IsoPentane</td>
<td>14,000</td>
<td>3,000</td>
<td>33,000</td>
<td>200,000</td>
</tr>
<tr>
<td>Hexanes</td>
<td>12,000</td>
<td>260</td>
<td>2,900</td>
<td>8,600</td>
</tr>
</tbody>
</table>

https://cameochemicals.noaa.gov
Plume Cross Section Concentration

Ground Level

5 Meters Above the Ground
Plume Centerline Concentration

Graph showing concentration (ppm) as a function of downwind distance (feet) for different compounds (Propane, Ethane, Butane) in Summer and Winter conditions.
Plume Height of Max Concentration

- Propane (Summer)
- Propane (Winter)
- Ethane (Summer)
- Ethane (Winter)
- Butane

Distance from Source (feet)

Height Above Ground (feet)
Applying Results for the Whole Pipeline
## Overall Max Distance by Season/Threshold

<table>
<thead>
<tr>
<th>Threshold Of Concern</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Explosive Limit</td>
<td>3,900</td>
<td>4,200</td>
</tr>
<tr>
<td>Level-1</td>
<td>8,200</td>
<td>9,100</td>
</tr>
<tr>
<td>Level-2</td>
<td>7,100</td>
<td>7,800</td>
</tr>
<tr>
<td>Level-3</td>
<td>2,400</td>
<td>2,600</td>
</tr>
</tbody>
</table>
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Liquid Plume Modeling

- OILMAP Land™ ArcGIS Extension

- Total liquid pool volume simulated at interval along pipeline

- Determines trajectory of spill over land, in streams, and spreading over lake surface
Surface Water Transport Model

Evaporation

Flow

Evaporation

Oil Retained on Shoreline

Lake
Liquid Plume Model Inputs

- Environmental Data – air temperature, wind speed
- Oil Characteristics – physical, chemical properties
Liquid Plume Model Outputs

- Spills Terminate on Land
- Oil Enters a Stream
- Oiled Lake

Map of spill points and plume outputs over time.
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Evaporation from Liquid Plumes

- Repeat the atmospheric dispersion modeling based on an evaporating pool

- Updated inputs:
  - Volume of pooled liquid
  - Surface area of the liquid pool (from liquid pool modeling)
  - Seasonal variability (temperature and wind)
  - Duration of the liquid pool
Evaporation from Liquid Plumes

- Rate of vaporization much lower than initial vapor release.
- Vapor concentrations drop below thresholds after a short distance and might not ever exceed thresholds.
Overall Results
From Modeling Results to HCA Segments
From HCA Segments to the EFRD Study

What is an EFRD?
- Remote Operated Valve (ROV) or a Check Valve
- Protect high consequence areas (HCAs)

Why is an EFRD so important to a pipeline?
- Topography or elevation profile
- Swiftness of shutdown
- Reduce drain down volumes
Factors Considered:
- Swiftness of leak detection and pipeline shutdown capabilities
- Type of commodity carried
- Rate of potential leakage
- Volume that can be released
- Topography or pipeline profile
- Location of nearest response personnel
- Benefits expected by reducing the spill size
Summary

- Releases from HVL pipelines can result in dangerous vapor clouds and possibly liquid spill plumes.
- Identifying HCA “could affect” segments may require both atmospheric dispersion modeling and liquid plume modeling.
- Risk from HVL releases can be reduced through strategic placement of EFRDs.
Operating a Successful Business Model

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