Vapor Recovery Tower/ VRU Configuration

Lessons Learned from Natural Gas STAR

Occidental Petroleum Corporation and California Independent Petroleum Association

Producers Technology Transfer Workshop
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epa.gov/gasstar
Vapor Recovery: Agenda

- Methane Losses
- Methane Savings
- Is Recovery Profitable?
- Industry Experience
- Lessons Learned
- Discussion
Methane Losses from Storage Tanks

- Storage tanks are responsible for 4% of methane emissions in natural gas and oil production sector.
- 96% of tank losses occur from tanks without vapor recovery.

Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 - 2005

- Offshore Operations: 34 Bcf
- Dehydrators and Pumps: 17 Bcf
- Gas Engine Exhaust: 12 Bcf
- Well Venting and Flaring: 9 Bcf
- Meters and Pipeline Leaks: 9 Bcf
- Pneumatic Devices: 57 Bcf
- Other Sources: 12 Bcf
- Storage Tank Venting: 6 Bcf

Bcf = billion cubic feet
Sources of Methane Losses

- A storage tank battery can vent 4,900 to 96,000 thousand cubic feet (Mcf) of natural gas and light hydrocarbon vapors to the atmosphere each year
  - Vapor losses are primarily a function of oil throughput, gravity, and gas-oil separator pressure

- Flash losses
  - Occur when crude is transferred from a gas-oil separator at higher pressure to a storage tank at atmospheric pressure

- Working losses
  - Occur when crude levels change and when crude in tank is agitated

- Standing losses
  - Occur with daily and seasonal temperature and barometric pressure changes
Methane Savings: Vapor Recovery

- Vapor recovery can capture up to 95% of hydrocarbon vapors from tanks
- Recovered vapors have higher heat content than pipeline quality natural gas
- Recovered vapors are more valuable than natural gas and have multiple uses
  - Re-inject into sales pipeline
  - Use as on-site fuel
  - Send to processing plants for recovering valuable natural gas liquids
Types of Vapor Recovery Units

- Conventional vapor recovery units (VRUs)
  - Use rotary or vane compressor to suck vapors out of atmospheric pressure storage tanks
  - Scroll compressors are new to this market
  - Require electrical power or engine driver

- Venturi ejector vapor recovery units (EVRU™) or Vapor Jet
  - Use Venturi jet ejectors in place of rotary compressors
  - Contain no moving parts
  - EVRU™ requires a source of high pressure motive gas and intermediate pressure discharge system
  - Vapor Jet requires a high pressure water motive
Conventional Vapor Recovery Unit

Source: Evans & Nelson (1968)
Vapor Recovery Installations
Venturi Jet Ejector*

- **High-Pressure Motive Gas** (~850 psig)
- **Low-Pressure Vent Gas from Tanks** (0.10 to 0.30 psig)
- **Flow Safety Valve**
- **Pressure Indicator**
- **Temperature Indicator**
- **Discharge Gas** (~40 psia)
- **Suction Pressure** (-0.05 to 0 psig)

*EVRU™ Patented by COMM Engineering

Adapted from SRI/USEPA-GHG-VR-19

psig = pound per square inch, gauge
psia = pounds per square inch, absolute
Vapor Recovery with Ejector

9,000 Mcf/day Gas
5,000 barrels/day Oil

5,000 Mcf/day Gas
5,000 barrels/day Oil

LP Separator

Compressor

6,200 Mcf/day

(19 Mcf/day incremental fuel)

Ratio Motive / Vent = 3
= 900/300

281 Mcf/day Net Recovery

900 Mcf/day

300 Mcf/day Gas

Ejector

40 psig

Gas to Sales
@ 1000 psig

281 Mcf/day Net Recovery

300 Mcf/day Gas

Mcf = Thousand cubic feet

Oil & Gas Well

Oil

Crude Oil Stock Tank

Oil to Sales

Oil
Vapor Jet System*

*Patented by Hy-Bon Engineering
Vapor Jet System*

- Utilizes produced water in closed loop system to effect gas gathering from tanks
- Small centrifugal pump forces water into Venturi jet, creating vacuum effect
- Limited to gas volumes of 77 Mcf/day and discharge pressure of 40 psig

*Patented by Hy-Bon Engineering
Criteria for Vapor Recovery Unit Locations

- Steady source and sufficient quantity of losses
  - Crude oil stock tank
  - Flash tank, heater/treater, water skimmer vents
  - Gas pneumatic controllers and pumps

- Outlet for recovered gas
  - Access to low pressure gas pipeline, compressor suction, or on-site fuel system

- Tank batteries not subject to air regulations
Quantify Volume of Losses

- Estimate losses from chart based on oil characteristics, pressure, and temperature at each location (± 50%)

- Estimate emissions using the E&P Tank Model (± 20%)

- Engineering Equations – Vasquez Beggs (± 20%)

- Measure losses using recording manometer and well tester or ultrasonic meter over several cycles (± 5%)

  - This is the best approach for facility design
Estimated Volume of Tank Vapors

Vapor Vented from Tanks, cubic foot / barrel
Gas/Oil Ratio

Pressure of Vessel Dumping to Tank (Psig)

API Gravities

10 20 30 40 50 60 70 80

Under 30° API

30° API to 39° API

40° API and Over

°API = API gravity
Final Stage of Separation

Atmospheric tanks may emit large amounts of tank vapors at relatively low separator pressure

Vasquez-Beggs Equation

\[
GOR = A \times (G_{\text{flash gas}}) \times (P_{\text{sep}} + 14.7)^B \times \exp\left(\frac{C \times G_{\text{oil}}}{T_{\text{sep}} + 460}\right)
\]

where,
- \(G_{\text{OR}}\) = Ratio of flash gas production to standard stock tank barrels of oil produced, in scf/bbl oil (barrels of oil corrected to 60°F)
- \(G_{\text{flash gas}}\) = Specific gravity of the tank flash gas, where \(a_{\text{r}} = 1\). A suggested default value for \(G_{\text{flash gas}}\) is 1.22 (TNRCC, Vasquez, 1980)
- \(G_{\text{oil}}\) = API gravity of stock tank oil at 60°F
- \(P_{\text{sep}}\) = Pressure in separator, in psig
- \(T_{\text{sep}}\) = Temperature in separator, °F

For \(G_{\text{oil}} \leq 30^\circ\text{API}\), \(A = 0.0362;\ B = 1.0937;\ \)and \(C = 25.724\)

For \(G_{\text{oil}} > 30^\circ\text{API}\), \(A = 0.0178;\ B = 1.187;\ \)and \(C = 23.931\)

Example for Huntington Beach Crude
- \(G_{\text{oil}}\) = 20.7° API
- \(G_{\text{flash gas}}\) = 1.22
- \(T_{\text{sep}}\) = 100°F
- \(P_{\text{sep}}\) = 3 psig
- \(GOR = 2.6\ \text{scf/bbl}\)

psig – pounds per square inch, gauge
scf – standard cubic feet
bbl – barrels
What is the Recovered Gas Worth?

- Value depends on heat content of gas
- Value depends on how gas is used
  - On-site fuel
    - Valued in terms of fuel that is replaced
  - Natural gas pipeline
    - Measured by the higher price for rich (higher heat content) gas
  - Gas processing plant
    - Measured by value of natural gas liquids and methane, which can be separated
Value of Recovered Gas

- Gross revenue per year = \((Q \times P \times 365) + NGL\)

- \(Q\) = Rate of vapor recovery (Mcf per day)
- \(P\) = Price of natural gas
- \(NGL\) = Value of natural gas liquids
## Value of Natural Gas Liquids

<table>
<thead>
<tr>
<th></th>
<th>1 Btu/gallon</th>
<th>2 MMBtu/gallon</th>
<th>3 $/gallon</th>
<th>4 $/MMBtu&lt;sup&gt;1,2,3&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>59,755</td>
<td>0.06</td>
<td>0.43</td>
<td>7.15</td>
</tr>
<tr>
<td>Ethane</td>
<td>74,010</td>
<td>0.07</td>
<td>0.64</td>
<td>9.14</td>
</tr>
<tr>
<td>Propane</td>
<td>91,740</td>
<td>0.09</td>
<td>0.98</td>
<td>10.89</td>
</tr>
<tr>
<td>n Butane</td>
<td>103,787</td>
<td>0.10</td>
<td>1.32</td>
<td>13.20</td>
</tr>
<tr>
<td>iso Butane</td>
<td>100,176</td>
<td>0.10</td>
<td>1.42</td>
<td>14.20</td>
</tr>
<tr>
<td>Pentanes+</td>
<td>105,000</td>
<td>0.11</td>
<td>1.50</td>
<td>13.63</td>
</tr>
</tbody>
</table>

### Table 1: Value of Natural Gas Liquids

<table>
<thead>
<tr>
<th></th>
<th>5 Btu/cf</th>
<th>6 MMBtu/Mcf</th>
<th>7 $/Mcf&lt;sup&gt;2&lt;/sup&gt; (=4*6)</th>
<th>8 $/MMBtu</th>
<th>9 Vapor Composition</th>
<th>10 Mixture MMBtu/Mcf</th>
<th>11 Value ($/Mcf)&lt;sup&gt;3&lt;/sup&gt; (=8*10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>1,012</td>
<td>1.01</td>
<td>$7.22</td>
<td>7.15</td>
<td>82%</td>
<td>0.83</td>
<td>$5.93</td>
</tr>
<tr>
<td>Ethane</td>
<td>1,773</td>
<td>1.77</td>
<td>$16.18</td>
<td>9.14</td>
<td>8%</td>
<td>0.14</td>
<td>$1.28</td>
</tr>
<tr>
<td>Propane</td>
<td>2,524</td>
<td>2.52</td>
<td>$27.44</td>
<td>10.89</td>
<td>4%</td>
<td>0.10</td>
<td>$1.09</td>
</tr>
<tr>
<td>n Butane</td>
<td>3,271</td>
<td>3.27</td>
<td>$43.16</td>
<td>13.20</td>
<td>3%</td>
<td>0.10</td>
<td>$1.32</td>
</tr>
<tr>
<td>iso Butane</td>
<td>3,261</td>
<td>3.26</td>
<td>$46.29</td>
<td>14.20</td>
<td>1%</td>
<td>0.03</td>
<td>$0.43</td>
</tr>
<tr>
<td>Pentanes+</td>
<td>4,380</td>
<td>4.38</td>
<td>$59.70</td>
<td>13.63</td>
<td>2%</td>
<td>0.09</td>
<td>$1.23</td>
</tr>
<tr>
<td>Total</td>
<td>1,289</td>
<td></td>
<td>$11.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 – Natural Gas Price assumed at $7.15/MMBtu as on Mar 16, 2006 at Henry Hub
2 – Prices of Individual NGL components are from Platts Oilgram for Mont Belvieu, TX January 11, 2006
3 – Other natural gas liquids information obtained from Oil and Gas Journal, Refining Report, March 19, 2001, p. 83

Btu = British Thermal Units, MMBtu = Million British Thermal Units, Mcf = Thousand Cubic Feet
## Cost of a Conventional VRU

<table>
<thead>
<tr>
<th>Capacity (Mcf/day)</th>
<th>Compressor Horsepower</th>
<th>Capital Costs ($)</th>
<th>Installation Costs ($)</th>
<th>O&amp;M Costs ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>5 to 10</td>
<td>20,421</td>
<td>10,207 to 20,421</td>
<td>7,367</td>
</tr>
<tr>
<td>50</td>
<td>10 to 15</td>
<td>26,327</td>
<td>13,164 to 26,327</td>
<td>8,419</td>
</tr>
<tr>
<td>100</td>
<td>15 to 25</td>
<td>31,728</td>
<td>15,864 to 31,728</td>
<td>10,103</td>
</tr>
<tr>
<td>200</td>
<td>30 to 50</td>
<td>42,529</td>
<td>21,264 to 42,529</td>
<td>11,787</td>
</tr>
<tr>
<td>500</td>
<td>60 to 80</td>
<td>59,405</td>
<td>29,703 to 59,405</td>
<td>16,839</td>
</tr>
</tbody>
</table>

Cost information provided by United States Natural Gas STAR companies and VRU manufacturers, 2006 basis.
# Is Recovery Profitable?

## Financial Analysis for a Conventional VRU Project

<table>
<thead>
<tr>
<th>Peak Capacity (Mcf/day)</th>
<th>Installation &amp; Capital Costs$^1$ ($)</th>
<th>O&amp;M Costs ($/year)</th>
<th>Value of Gas$^2$ ($/year)</th>
<th>Annual Savings ($)</th>
<th>Simple Payback (months)</th>
<th>Internal Rate of Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>$35,738</td>
<td>$7,367</td>
<td>$51,465</td>
<td>$44,098</td>
<td>10</td>
<td>121%</td>
</tr>
<tr>
<td>50</td>
<td>$46,073</td>
<td>$8,419</td>
<td>$102,930</td>
<td>$94,511</td>
<td>6</td>
<td>204%</td>
</tr>
<tr>
<td>100</td>
<td>$55,524</td>
<td>$10,103</td>
<td>$205,860</td>
<td>$195,757</td>
<td>4</td>
<td>352%</td>
</tr>
<tr>
<td>200</td>
<td>$74,425</td>
<td>$11,787</td>
<td>$411,720</td>
<td>$399,933</td>
<td>3</td>
<td>537%</td>
</tr>
<tr>
<td>500</td>
<td>$103,969</td>
<td>$16,839</td>
<td>$1,029,300</td>
<td>$1,012,461</td>
<td>2</td>
<td>974%</td>
</tr>
</tbody>
</table>

$^1$ – Unit cost plus estimated installation of 75% of unit cost  
$^2$ – $11.28 \times \frac{1}{2}$ peak capacity x 365, Assumed price includes Btu enriched gas (1.289 MMBtu/Mcf)
## Industry Experience

Top five United States companies for emissions reductions using VRUs in 2005

<table>
<thead>
<tr>
<th>Company</th>
<th>2005 Annual Reductions (Mcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company 1</td>
<td>1,346,208</td>
</tr>
<tr>
<td>Company 2</td>
<td>313,753</td>
</tr>
<tr>
<td>Company 3</td>
<td>160,650</td>
</tr>
<tr>
<td>Company 4</td>
<td>54,597</td>
</tr>
<tr>
<td>Company 5</td>
<td>31,239</td>
</tr>
</tbody>
</table>
Industry Experience: Anadarko

Vapor Recover Tower (VRT)

- Add separation vessel between heater treater or low pressure separator and storage tanks that operates at or near atmospheric pressure
  - Operating pressure range: 1 psi to 5 psi
- Compressor (VRU) is used to capture gas from VRT
- Oil/Condensate gravity flows from VRT to storage tanks
  - VRT insulates the VRU from gas surges with stock tank level changes
  - VRT more tolerant to higher and lower pressures
  - Stable pressure allows better operating factor for VRU
Industry Experience: Anadarko

- VRT reduces pressure drop from approximately 50 psig to 1-5 psig
  - Reduces flashing losses
  - Captures more product for sales
  - Anadarko netted between $7 to $8 million from 1993 to 1999 by utilizing VRT/VRU configuration

- Equipment Capital Cost: $11,000

- Standard size VRTs available based on oil production rate
  - 20” x 35’
  - 48” x 35’

- Anadarko has installed over 300 VRT/VRUs since 1993 and continues on an as needed basis
VRT/VRU Photos

Courtesy of Anadarko
VRT/VRU Photos

Courtesy of Anadarko
Industry Experience: Oxy

- Oxy Case Study - Vapor Recovery
  - Wasson Tank Battery (CDU 1 & 2)
  - Denver City, Texas
  - Installed in 2004

- Oxy purchased two vapor recovery units in August 2004 for capturing vapors from two separate tank batteries at their Wasson facility

- Each battery produces approximately 450 Mcf/day of tank vapors, which Oxy needed to gather and compress into a 45 psig sales line

- Due to the low discharge pressure, Oxy selected rotary vane compressor packages capable of moving 500 Mcf/day

- In order to minimize maintenance, Oxy selected electric drive units
  - 75 horsepower electric motors on each unit
Oxy Wasson Tank Battery 1 – CDU 1
## Industry Experience: Oxy

<table>
<thead>
<tr>
<th>Cost per site</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost:</td>
<td>$92,500</td>
</tr>
<tr>
<td>Installation Cost:</td>
<td>$9,500</td>
</tr>
<tr>
<td>Installed Cost:</td>
<td>$102,000</td>
</tr>
<tr>
<td>Gas Volume (Mcf/day):</td>
<td>450</td>
</tr>
<tr>
<td>Value at $7/Mcf:</td>
<td>$3,150</td>
</tr>
<tr>
<td>Annual Revenue:</td>
<td>$1,149,750</td>
</tr>
<tr>
<td>(with no BTU adjustment and no liquid sales)</td>
<td></td>
</tr>
<tr>
<td>Monthly Incremental Revenue:</td>
<td>$95,812</td>
</tr>
<tr>
<td>Payback (in months):</td>
<td>1.06</td>
</tr>
</tbody>
</table>
Lessons Learned

- Vapor recovery can yield generous returns when there are market outlets for recovered gas
  - Recovered high heat content gas has extra value
  - Vapor recovery technology can be highly cost-effective in most general applications
  - Venturi jet models work well in certain niche applications, with reduced operating and maintenance costs
- Potential for reduced compliance costs can be considered when evaluating economics of VRU, EVRU™, or Vapor Jet
Lessons Learned (continued)

- VRU should be sized for maximum volume expected from storage tanks (rule-of-thumb is to double daily average volume)
- Rotary vane, screw or scroll type compressors recommended for VRUs where Venturi ejector jet designs are not applicable
- EVRU™ recommended where there is a high pressure gas compressor with excess capacity
- Vapor Jet recommended where there is produced water, less than 75 Mcf per day gas and discharge pressures below 40 psig
Discussion

- Industry experience applying these technologies and practices
- Limitations on application of these technologies and practices
- Actual costs and benefits