Reducing Emissions from Compressor Seals

Lessons Learned from Natural Gas STAR

Transmission Technology Transfer Workshop

Duke Energy Gas Transmission
Interstate Natural Gas Association of America (INGAA) and EPA’s Natural Gas STAR Program

September 22, 2004
Compressor Seals: Agenda

- Methane Losses
- Methane Recovery
- Is Recovery Profitable?
- Industry Experience
- Discussion Questions
Methane Losses from Transmission and Storage

- Transmission and storage sector responsible for 96 billion cubic feet (Bcf) in methane emissions

---

<table>
<thead>
<tr>
<th>Category</th>
<th>Methane Losses (Bcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>149</td>
</tr>
<tr>
<td>Processing</td>
<td>36</td>
</tr>
<tr>
<td>Distribution</td>
<td>77</td>
</tr>
<tr>
<td>Trans &amp; Storage</td>
<td>96</td>
</tr>
<tr>
<td>Oil Downstream</td>
<td>2</td>
</tr>
<tr>
<td>Oil Downstream Emissions Reductions</td>
<td>1</td>
</tr>
</tbody>
</table>

Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 - 2002

Reducing Emissions, Increasing Efficiency, Maximizing Profits
Methane Losses from Compressor Seals

Compressor seals contribute 50% of transmission and storage emissions

- 40 Bcf from reciprocating compressors
- 8 Bcf from centrifugal compressors

Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 - 2002
Compressor Seals
What is the problem?

★ Compressor seals account for 13% of natural gas industry emissions

◆ Over 45,000 compressors in the natural gas industry
◆ Over 8,500 compressors in gas transmission sector
Reducing Emissions, Increasing Efficiency, Maximizing Profits

Methane Losses from Reciprocating Compressors

Reciprocating compressor rod packing leaks some gas by design:

- Newly installed packing may leak 60 cubic feet per hour (cf/h)
- Worn packing has been reported to leak up to 900 cf/h

(Side View, Cut in Half)
Reciprocating Compressor Rod Packing

★ A series of flexible rings fit around the shaft to prevent leakage
★ Leakage still occurs through nose gasket, between packing cups, around the rings and between rings and shaft

Two Rings (In Three Segments)
Springs
Lubrication
Gas Leakage
Flange
Packing Cup
(Piston Rod)
Cylinder Wall
High Pressure Gas Inside Cylinder
(Side View, Cut in Half)
Gas STAR Partners Reduce Emission with Economic Rod Packing Replacement

Decision Process

1. Monitor and record baseline packing leakage and piston rod wear
2. Compare current leak rate to initial leak rate to determine leak reduction expected
3. Assess costs of replacements
4. Determine economic replacement threshold
5. Replace packing and rods where cost-effective

Reducing Emissions, Increasing Efficiency, Maximizing Profits
Methane Recovery Through Economic Rod Packing Replacement

★ Step 1: Monitor and record baseline leakage and rod wear
  ◆ Establishing baseline leak rates and monitoring rod wear can help to track leakage and evaluate economics

★ Step 2: Compare current leak rate to initial leak rate to determine leak reduction expected
  ◆ Leak Reduction Expected (LRE) = Current Leak Rate (CL) – Initial Leak Rate (IL)
  ◆ Example: The current leak rate is measured as 100 cf/h, the same component leaked 11.5 cf/h when first installed
    LRE = 100 cf/h – 11.5 cf/h
    LRE = 88.5 cf/h
Methane Recovery Through Economic Rod Packing Replacement

☆ Step 3: Assess costs of replacements

◆ A set of rings: $500 to $800
  (with cups and case) $1500 to $2500
◆ Rods: $1800 to $3500

☆ Step 4: Determine economic replacement threshold

◆ Partners can determine economic threshold for all replacements

Economic Replacement Threshold (scfh) = \[ \frac{CR \times DF \times 1,000}{(H \times GP)} \]

Where:

CR = Cost of replacement ($)
DF = Discount factor (%) @ interest i
H = Hours of compressor operation per year
GP = Gas price ($/Mcf)

DF = \[ \frac{i(1+i)^n}{(1+i)^n - 1} \]
Is Recovery Profitable?

★ Step 5: Replace packing and rods when cost-effective

◆ Example: Rings Only

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rings</td>
<td>$1,200</td>
<td>Rod:</td>
</tr>
<tr>
<td>Operating</td>
<td>8,000 hrs/yr</td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rings:</td>
<td>$1,200</td>
<td>Rod:</td>
</tr>
<tr>
<td>Gas:</td>
<td>$3/Mcf</td>
<td></td>
</tr>
</tbody>
</table>

Based on 10% interest rate
Mcf = thousand cubic feet, scfh = standard cubic feet per hour

<table>
<thead>
<tr>
<th>Leak Reduction Expected (scfh)</th>
<th>Payback Period (yrs)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leak Reduction Expected (scfh)</th>
<th>Payback Period (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>376</td>
<td>1</td>
</tr>
<tr>
<td>197</td>
<td>2</td>
</tr>
<tr>
<td>137</td>
<td>3</td>
</tr>
<tr>
<td>108</td>
<td>4</td>
</tr>
<tr>
<td>90</td>
<td>5</td>
</tr>
</tbody>
</table>
Industry Experience

- One partner reported replacing worn rod packing rings on 15 compressor units
- Estimated gas savings of 7,000 Mcf or $21,000 @ $3/Mcf
- Cost including materials and labor of $17,000
- Payback period of less than one year
Methane Losses from Centrifugal Compressors

- Centrifugal compressor wet seals leak little gas at the seal face
  - Seal oil degassing may vent 40 to 200 cubic feet per minute (cf/m) to the atmosphere
  - A Natural Gas STAR partner reported wet seal emissions of 75 Mcf/day (52 cf/m)
Centrifugal Compressor Wet Seals

- High pressure seal oil is circulated between rings around the compressor shaft
- Gas absorbs in the oil on the inboard side
- Little gas leaks through the oil seal
- Seal oil degassing vents methane to the atmosphere
Gas STAR Partners Reduce Emissions with Dry Seals

★ Dry seal springs press the stationary ring in the seal housing against the rotating ring when the compressor is not rotating
★ At high rotation speed, gas is pumped between the seal rings creating a high pressure barrier to leakage
★ Only a very small amount of gas escapes through the gap
★ 2 seals are often used in tandem
Methane Recovery with Dry Seals

☆ Dry seals typically leak at a rate of only 0.5 to 3 cf/m

◆ Significantly less than the 40 to 200 cf/m emissions from wet seals

☆ These savings translate to approximately $48,960 to $279,360 in annual gas value
Other Benefits with Dry Seals

★ Aside from gas savings and reduced emissions, dry seals also:

- **Lower operating cost**
  - Dry seals do not require seal oil make-up
- **Reduced power consumption**
  - Wet seals require 50 to 100 kiloWatt hours (kW/hr) for ancillary equipment while dry seals need only 5 kW/hr
- **Improve reliability**
  - More compressor downtime is due to wet seals
- **Eliminate seal oil leakage into the pipelines**
  - Dry seals lower drag in pipelines (and horsepower to overcome)
Gas STAR Partners Reduce Emissions with Dry Seal Replacement

Decision Process

1. Identify candidates for wet seal replacement
2. Estimate savings of dry seal retrofit
3. Determine costs for conversion to dry seals
4. Compare costs to savings
Decision Process to Replace Seals

🌟 Step 1: Identify candidates for replacement

- Dry seals are routinely used for compressors operating up to 1,500 pounds per square inch (psi), up to 400° Fahrenheit

🌟 Step 2: Estimate savings from a dry seal

- Gas savings between 34 to 196 cf/m
- Other dry seal benefits ≈ $63,000/yr

1. Reduced seal power losses = $13,900
2. Reduced oil pump/fan losses = $4,000
3. Increased pipeline flow efficiency = $26,600
4. Reduced oil losses = $3,500
5. Reduced O&M, downtime = $15,000
Decision Process to Replace Seals

★ Step 3: Determine dry seal conversion costs

- Dry seals cost $5,000 to $6,000 per inch of shaft diameter or $8,000 to $10,000 for tandem seals
- Beam compressors require two seals, one at each end
- Overhung compressors require one seal at the inboard end
### Decision Process to Replace Seals

**Step 4: Compare costs and savings for a 6-inch shaft beam compressor**

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Dry Seal ($)</th>
<th>Wet Seal ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Implementation Costs</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seal costs (2 dry @ $10,000/ft, w/testing)</td>
<td>120,000</td>
<td></td>
</tr>
<tr>
<td>Seal costs (2 wet @ $5,000/ft)</td>
<td></td>
<td>60,000</td>
</tr>
<tr>
<td>Other costs (engineering, equipment installation)</td>
<td>120,000</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total Implementation Costs</strong></td>
<td>240,000</td>
<td>60,000</td>
</tr>
<tr>
<td><strong>Annual O&amp;M</strong></td>
<td>10,000</td>
<td>73,000</td>
</tr>
<tr>
<td><strong>Annual methane emissions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 dry seals @ total 6 scfm</td>
<td>8,640</td>
<td></td>
</tr>
<tr>
<td>2 wet seals at total 100 scfm</td>
<td></td>
<td>144,000</td>
</tr>
<tr>
<td><strong>Total Costs Over 5-Year Period ($)</strong></td>
<td>333,200</td>
<td>1,145,000</td>
</tr>
<tr>
<td><strong>Total Dry Seal Savings Over 5 Years:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savings ($)</td>
<td>811,800</td>
<td></td>
</tr>
<tr>
<td>Methane Emissions Reductions (Mcf) (at 45,120 Mcf/yr)</td>
<td>225,600</td>
<td></td>
</tr>
</tbody>
</table>

Flowserve Corporation

*Reducing Emissions, Increasing Efficiency, Maximizing Profits*
Is Recovery Profitable?

★ Replacing wet seals in a 6 inch shaft beam compressor operating 8,000 hr/yr

◆ Net Present Value = $531,940
  ▪ Assuming a 10% discount over 5 years
◆ Internal Rate of Return = 86%
◆ Payback Period = 14 months
  ▪ Ranges from 8 to 24 months based on wet seal leakage rate

★ Economics are better for new installations

◆ Vendors report that 90% of compressors sold to the natural gas industry are centrifugal with dry seals
Industry Experience

★ One Gas STAR partner replaced a wet seal with a dry seal and reduced emissions by 97%

★ Dry seal leaked 2 Mcf/d versus wet seal emissions of 75 Mcf/d
Discussion Questions

☆ To what extent have you replaced rod packing or seals in your reciprocating and centrifugal compressors?

☆ How can the Lessons Learned study be improved upon or altered for use in your operation(s)?

☆ What are the barriers (technological, economic, lack of information, regulatory, etc.) that are preventing you from implementing this technology?