Reducing Methane Emissions from Centrifugal and Reciprocating Compressors

Seminar with Russian Independent Oil and Gas Producers on Methane Mitigation Technologies and Strategies
October 4, 2010, Moscow, Russia

Don Robinson, Vice President
ICF International
Compressor Seals: Agenda

- U.S. Methane Emissions from Compressor Seals
- Centrifugal Compressor Wet Seals
  - Methane Losses
  - Solutions
  - Economics
  - Industry Experience / More Opportunities
- Reciprocating Compressor Rod Packing
  - Methane Losses
  - Solutions
  - Economics
  - More Opportunities / Industry Experience
- Contacts and Further Information
2008 Transmission Sector Methane Emissions (97 Bcf)

- Reciprocating Compressors: 40 Bcf
- Gas Engine Exhaust: 11 Bcf
- Pneumatic Devices: 11 Bcf
- Centrifugal Compressors: 8 Bcf
- Station Venting: 8 Bcf
- Pipeline Leaks: 7 Bcf
- Station Fugitives: 7 Bcf
- Other Sources: 5 Bcf
- Other Sources: 5 Bcf

Bcf = billion cubic feet

Methane Losses from Centrifugal Compressors

- Centrifugal compressor wet seals leak little gas at the seal face
  - The majority of methane emissions occur through seal oil degassing which is vented to the atmosphere
  - Seal oil degassing may vent 1.1 to 5.7 m³/minute to the atmosphere
  - One Natural Gas STAR Partner reported emissions as high as 2,124 m³/day
Centrifugal Compressor Wet Seals

- High pressure seal oil circulates between rings around the compressor shaft
- Oil absorbs the gas on the inboard side
  - Little gas leaks through the oil seal
  - Seal oil degassing vents methane to the atmosphere

Source: PEMEX
Wet Seals Solution: Dry Seals

- Dry seal springs press stationary ring in seal housing against rotating ring when compressor is not rotating.
- At high rotation speed, gas is pumped between seal rings by grooves in rotating ring 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.
- Can operate for compressors up to 206 atmospheres (atm) safely.
Methane Savings through Dry Seals

- Dry seals typically leak at a rate of only 0.8 to 5.1 m$^3$/hour (0.01 to 0.09 m$^3$/ minute)
  - Significantly less than the 1.1 to 5.7 m$^3$/minute emissions from wet seals
- Gas savings translate to approximately RUB 5,000,000 to RUB 30,000,000 at RUB 11,360/Mcm$^1$

$^1$Mcm = thousand cubic meters
# Economics of Replacing Seals

- Compare costs and savings for a 15.2 cm (6-inch) shaft beam compressor

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Dry Seal (RUB)</th>
<th>Wet Seal (RUB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Implementation costs</strong>¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seal costs (2 dry @ RUB 414,720/shaft-inch, with testing)</td>
<td>4,976,640</td>
<td></td>
</tr>
<tr>
<td>Seal costs (2 wet @ RUB 207,390/shaft-inch)</td>
<td></td>
<td>2,488,680</td>
</tr>
<tr>
<td>Other costs (engineering, equipment installation)</td>
<td>4,976,640</td>
<td>0</td>
</tr>
<tr>
<td>Total implementation costs</td>
<td>9,953,280</td>
<td>2,488,680</td>
</tr>
<tr>
<td><strong>Annual operating and maintenance</strong></td>
<td>433,150</td>
<td>3,145,730</td>
</tr>
<tr>
<td><strong>Annual methane emissions</strong> (@ RUB 11,360/thousand m³; 8,000 hours/year)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 dry seals at a total of 12 m³/hour</td>
<td>1,090,560</td>
<td></td>
</tr>
<tr>
<td>2 wet seals at a total of 168 m³/hour</td>
<td></td>
<td>15,267,840</td>
</tr>
<tr>
<td><strong>Total costs over 5-year period</strong></td>
<td>12,119,030</td>
<td>18,217,330</td>
</tr>
<tr>
<td><strong>Total dry seal savings over 5 years</strong></td>
<td>6,098,300</td>
<td></td>
</tr>
</tbody>
</table>

¹Flowserve Corporation (updated costs and savings)
Methane to Markets

Industry Experience – PEMEX (Mexican Production Company)

- PEMEX had 46 compressors with wet seals at a production site
- Converted three to dry seals
  - Cost RUB 13,639,680/compressor
  - Saves 580,500 m³/compressor/year
  - Saves RUB 6,594,480/compressor/year in gas
- 2.1 year payback from gas savings alone
- Plans for future dry seal installations

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1 All data based on Partners’ experiences and represented in U.S. economics, converted to Russian currency.
2 Gas price at RUB 11,360/Mcm
Industry Experience – Supersonic Gas Injector: TransCanada (Canadian Transmission Company)

- Developed for capturing very low pressure vent gases and re-injection into a high pressure gas stream without the use of rotating machinery

- Savings
  - 113,000 m³/year of gas savings from one compressor
  - Natural gas worth RUB 1,283,680/year/unit at RUB 11,360/Mcm
  - Zero operating cost

Source: TransCanada
More Opportunities

- Partners are identifying other technologies and practices to reduce emissions
- One partner degasses seal oil in an intermediate pressure drum, with the gas used:
  - As turbine fuel
  - As low pressure fuel
  - To flare
- Prevents most seal oil gas emissions from venting to atmosphere
- Less expensive capital costs compared to dry seals
- Partner reported emission reductions of 3.1 m³/minute (110 ft³/minute) \textit{per seal} when routing gas back to turbine fuel
More Opportunities—cont.

- Partner’s seal oil degassing vent recovery and use:

  *Note: New equipment in red*

  - Seal oil discharge pressure = 96.3 atm
  - New fuel pressure seal oil degassing drum and demister
  - Atmospheric seal oil degassing drum
  - Less gas vented to atmosphere
  - Seal oil circulation pump

  3 OPTIONS:
  - 4.4 atm Compressor turbine fuel
  - 1.8 atm Low pressure fuel gas
  - 18.0 atm Seal oil discharge pressure

  Partner’s seal oil degassing vent recovery and use:

  - Atmospheric seal oil degassing drum
  - Less gas vented to atmosphere
  - Seal oil circulation pump
More Opportunities—cont.

- Investment includes cost of:
  - Intermediate degassing drum
  - New piping
  - Gas demister/filter
  - Pressure regulator for fuel gas line

- Project summary:
  - Less capital intensive than dry seals
  - Reduce emissions while also improving site efficiency
  - Positive cash flow after less than a month

<table>
<thead>
<tr>
<th>PROJECT SUMMARY: CAPTURE AND USE OF SEAL OIL DEGASSING EMISSIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Requirements</td>
</tr>
<tr>
<td>• Centrifugal compressor with seal oil system</td>
</tr>
<tr>
<td>• Nearby use for low pressure fuel gas</td>
</tr>
<tr>
<td>• New intermediate pressure flash drum, fuel filter, pressure regulator</td>
</tr>
<tr>
<td>Capital &amp; Installation Costs</td>
</tr>
<tr>
<td>RUB 675,840¹</td>
</tr>
<tr>
<td>Annual Labor &amp; Maintenance Costs</td>
</tr>
<tr>
<td>Minimal</td>
</tr>
<tr>
<td>Methane saved</td>
</tr>
<tr>
<td>1.8 MMcm</td>
</tr>
<tr>
<td>Gas Price per Mcm</td>
</tr>
<tr>
<td>RUB 5,680</td>
</tr>
<tr>
<td>RUB 11,360</td>
</tr>
<tr>
<td>RUB 17,040</td>
</tr>
<tr>
<td>Value of Gas Saved</td>
</tr>
<tr>
<td>RUB 10,224,000</td>
</tr>
<tr>
<td>RUB 20,448,000</td>
</tr>
<tr>
<td>RUB 30,672,000</td>
</tr>
<tr>
<td>Payback Period in Months</td>
</tr>
<tr>
<td>0.8</td>
</tr>
<tr>
<td>0.4</td>
</tr>
<tr>
<td>0.3</td>
</tr>
</tbody>
</table>

¹Assuming a typical seal oil flow rate of 14.20 liters/minute (3.75 gallons/minute)
Compressor Seals: Agenda

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Methane Losses from Reciprocating Compressors

- Reciprocating compressor rod packing leaks some gas by design
  - Newly installed packing may leak 0.3 to 1.7 m³/hour
  - Worn packing has been reported to leak up to 25.5 m³/hour
Reciprocating Compressor Rod Packing

- A series of flexible rings fit around the shaft to prevent leakage
- Leakage may still occur through nose gasket, between packing cups, around the rings, and between rings and shaft
# Methane Losses from Rod Packing

| Source: Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations – PRCI/ GRI/ EPA PR-246-9526 |

## Emission from Running Compressor
- 24,600 m³/year-packing

## Emission from Idle/Pressurized Compressor
- 36,000 m³/year-packing

## Leakage from Packing Cup
- 19,500 m³/year-packing

## Leakage from Distance Piece
- 8,500 m³/year-packing

### Leakage from Rod Packing on Running Compressors

<table>
<thead>
<tr>
<th>Packing Type</th>
<th>Bronze</th>
<th>Bronze/Steel</th>
<th>Bronze/Teflon</th>
<th>Teflon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak Rate (m³/year)</td>
<td>17,300</td>
<td>15,700</td>
<td>37,300</td>
<td>5,900</td>
</tr>
</tbody>
</table>

### Leakage from Rod Packing on Idle/Pressurized Compressors

<table>
<thead>
<tr>
<th>Packing Type</th>
<th>Bronze</th>
<th>Bronze/Steel</th>
<th>Bronze/Teflon</th>
<th>Teflon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak Rate (m³/year)</td>
<td>17,400</td>
<td>N/A</td>
<td>36,500</td>
<td>5,400</td>
</tr>
</tbody>
</table>
Solution: Economic Replacement

- Measure rod packing leakage
  - When new packing installed–after worn-in
  - Periodically afterwards
- Determine cost of packing replacement
- Determine economic replacement threshold
  - Partners can determine economic threshold for all replacements
  - This is a capital recovery economic calculation
- Replace packing when leak reduction expected will pay back cost

Economic Replacement Threshold (m³/hour) = \( \frac{CR \times DF \times 1,000}{(H \times GP)} \)

Where:
- \( CR \) = Cost of replacement (RUB)
- \( DF \) = Discount factor at interest \( i \)
- \( H \) = Hours of compressor operation per year
- \( GP \) = Gas price RUB/thousand cubic meters

\[ DF = \frac{i(1+i)^n}{(1+i)^n - 1} \]
More Opportunities: Low Emission Packing (LEP)

- The side load eliminates clearance and maintains positive seal on cup face
- LEP is a static seal, not a dynamic seal. No pressure is required to activate the packing
- This design works in existing packing case with limited, to no modifications required
LEP Packing Configuration

Same
Orientation in Cup

LEP: Low Emissions Packing
Orientation of P303 Rings

Same
Reasons to Use LEP

- Upgrade is inexpensive
- Significant reduction of greenhouse gas is major benefit
- Refining, petrochemical, and air separation plants have used this design for many years to minimize fugitive emissions
Industry Experience – Northern Natural Gas (U.S. Transmission Company)

- Monitored emissions at two locations
  - Unit A leakage as high as 301 liters/minute (18 m³/hour)
  - Unit B leakage as high as 105 liters/minute (6 m³/hour)

- Installed low emission packing (LEP)
  - Testing is still in progress
  - After 3 months, leak rate showed zero leakage increase
Contact Information and Further Information

- More detail is available on these practices and over 80 others online at: epa.gov/gasstar/tools/recommended.html

- For further assistance, direct questions to:

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