Compressors: Agenda

- Centrifugal Compressors
  - Methane Losses
  - Methane Savings
  - Industry Experience

- Reciprocating Compressors
  - Methane Losses
  - Methane Savings
  - Industry Experience

- Discussion
2007 Production Sector Methane Emissions

Storage Tank Venting 5 Bcf
Well Venting and Flaring 7 Bcf
Meters and Pipeline Leaks 8 Bcf
Compressor Fugitives, Venting, and Engine Exhaust 12 Bcf
Dehydrators and Pumps 12 Bcf
Offshore Operations 29 Bcf
Pneumatic Devices 43 Bcf
Other Sources 7 Bcf


Note: Natural Gas STAR reductions from gathering and boosting operations are reflected in the production sector.

Compressor Methane Emissions
What is the problem?
Methane emissions from the ~42,400 compressors in the natural gas industry account for 118 Bcf/year or about 33% of all methane emissions from the natural gas industry.
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/minute) to the atmosphere
  - A Natural Gas STAR Partner reported wet seal emissions of 75 Mcf/day (52 cf/minute)

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
Natural 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.
- Sealing at high rotation speed pumps gas between the seal rings creating a high pressure barrier to leakage.
- Only a very small volume of gas escapes through the gap.
- Two seals are often used in tandem.
- Can operate for compressors up to 3,000 pounds per square inch gauge (psig) safely.

Methane Savings through Dry Seals

- Dry seals typically leak 0.5 to 3 cf/minute.
  - Significantly less than the 40 to 200 cf/minute emissions from wet seals.
- Gas savings translate to approximately $112,000 to $651,000 at $7/Mcf.
Economics of Replacing Seals

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 @ $13,500/shaft-inch, with testing)</td>
<td>$162,000</td>
<td>$81,000</td>
</tr>
<tr>
<td>Seal costs (2 wet @ $6,750/shaft-inch)</td>
<td>$162,000</td>
<td>$0</td>
</tr>
<tr>
<td>Other costs (engineering, equipment installation)</td>
<td>$324,000</td>
<td>$81,000</td>
</tr>
<tr>
<td><strong>Total implementation costs</strong></td>
<td>$81,000</td>
<td>$0</td>
</tr>
<tr>
<td><strong>Annual Operating and Maintenance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Annual Methane Emissions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 dry seals at a total of 6 cf/minute</td>
<td>$20,160</td>
<td>$336,000</td>
</tr>
<tr>
<td>2 wet seals at a total of 100 cf/minute</td>
<td>$336,000</td>
<td>$336,000</td>
</tr>
<tr>
<td><strong>Total Costs Over 5-Year Period</strong></td>
<td>$495,300</td>
<td>$2,273,000</td>
</tr>
<tr>
<td><strong>Total Dry Seal Savings Over 5 Years</strong></td>
<td>$1,777,700</td>
<td>$225,600</td>
</tr>
</tbody>
</table>

*Flowserve Corporation (updated costs and savings)*

Is Wet Seal Replacement Profitable?

Replacing wet seals in a 6 inch shaft beam compressor operating 8,000 hours/year

- Net present value = $1,337,769
  - Assuming a 10% discount over 5 years
- Internal rate of return = 129%
- Payback period = 10 months
  - Ranges from 3 to 11 months based on wet seal leakage rates between 40 and 200 cf/minute

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 – PEMEX

- PEMEX had 46 compressors with wet seals at its PGPB production site
- Converted three to dry seals
  - Cost $444,000/compressor
  - Saves 20,500 Mcf/compressor/year
  - Saves $126,690/compressor/year in gas
- 3.5 year payback from gas savings alone
- Plans for future dry seal installations

Source: PEMEX

Finding More Opportunities

- Partners are identifying other technologies and practices to reduce emissions
  - TransCanada has successfully conducted pilot studies on the use of an ejector to recover dry seal leakage
  - Prospective project not yet reported: route seal oil flash gas to low pressure fuel system
  - Reduces methane emissions from the significant source of centrifugal compressor wet seal oil degassing but without significant capital investment of dry seal retrofit

Source: TransCanada
TransCanada Experience: Supersonic Gas-Gas Ejector

Compressor Package Components
Winchell Lk

Dry seal panel, continuous gas venting by design

Supersonic Gas-Gas Ejector for Capturing Low Pressure Vent gases

Fuel Regulator (Fisher 310)

(Pin) 6000 kPa-a

3400 kPa-a

(Pout)

1200 kPa-a

(P1) 5000 kPa-a

400 kPa-a

(Leakage from Dry-Gas Seal)

(P2) (P3)
Supersonic Gas-Gas Ejector for Dry Gas Seal Leak Capture

Conceptual Flow Diagram

- Developed for capturing very low pressure vent gases and re-injection into a high pressure gas stream without the use of rotating machinery
- Savings
  - 4 MMcf/yr of gas savings from one compressor
  - Natural gas worth $28,000/yr/unit @$7/GJ
  - GHG emissions
  - Zero operating cost

Source: TransCanada
Finding More Opportunities

- **Wet Seal Degassing**
  - Potential new method to capture emissions from wet seal compressors
  - Can be more economical than replacing wet seals with dry seals

### POTENTIAL PROJECT EXAMPLE ECONOMICS: CAPTURE AND USE OF SEAL OIL DEGASSING EMISSIONS

| OPERATING REQUIREMENTS | • Centrifugal compressor with seal oil system
| | • Nearby use for low pressure fuel gas
| | • New intermediate pressure flash drum, fuel filter, pressure regulator
| CAPITAL & INSTALLATION COSTS | $22,000
| ANNUAL LABOR & MAINTENANCE COSTS | Minimal
| METHANE SAVED | 63 MMcf per year
| GAS PRICE PER Mcf | $3, $7, $10
| VALUE OF GAS SAVED | $189,000, $442,000, $631,000
| PAYBACK PERIOD IN MONTHS | 2, 1, 0.5

---

Finding More Opportunities

- **Wet Seal Degassing**
  - Requires nearby boiler or engine to make use of fuel gas
Compressors: Agenda

- Centrifugal Compressors
  - Methane Losses
  - Methane Savings
  - Industry Experience

- Reciprocating Compressors
  - Methane Losses
  - Methane Savings
  - Industry Experience

- Discussion

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/hour)
  - Worn packing has been reported to leak up to 900 cf/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

![Diagram of Reciprocating Compressor Rod Packing]

Impediments to Proper Sealing

**Ways packing case can leak**
- Nose gasket (no crush)
- Packing to rod (surface finish)
- Packing to cup (lapped surface)
- Packing to packing (dirt/lube)
- Cup to cup (out of tolerance)

**What makes packing leak?**
- Dirt or foreign matter (trash)
- Worn rod (.0015”/per inch dia.)
- Insufficient/too much lubrication
- Packing cup out of tolerance (≤ 0.002”)
- Improper break-in on startup
- Liquids (dilutes oil)
- Incorrect packing installed (backward or wrong type/style)
Methane Losses from Rod Packing

| Emission from Running Compressor | 99 cf/hour-packing |
| Emission from Idle/Pressurized Compressor | 145 cf/hour-packing |
| Leakage from Idle Compressor Packing Cup | 79 cf/hour-packing |
| Leakage from Idle Compressor Distance Piece | 34 cf/hour-packing |

| Leakage from Rod Packing on Running Compressors |
| Packing Type | Bronze | Bronze/Steel | Bronze/Teflon | Teflon |
| Leak Rate (cf/hour) | 70 | 63 | 150 | 24 |

| Leakage from Rod Packing on Idle/Pressurized Compressors |
| Packing Type | Bronze | Bronze/Steel | Bronze/Teflon | Teflon |
| Leak Rate (cf/hour) | 70 | N/A | 147 | 22 |

PRCI/ GRI/ EPA. Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations

Steps to Determine Economic Replacement

- Measure rod packing leakage
  - When new packing installed – after worn-in
  - Periodically afterwards
- Determine cost of packing replacement
- Calculate economic leak reduction
- Replace packing when leak reduction expected will pay back cost
Cost of Rod Packing Replacement

Assess costs of replacements

- A set of rings: $1,350 to $1,700
  (with cups and case) $2,025 to $3,375
- Rods: $2,430 to $13,500

Special coatings such as ceramic, tungsten carbide, or chromium can increase rod costs.

Source: CECO

Calculate Economic Leak Reduction

Determine economic replacement threshold

- Partners can determine economic threshold for all replacements
- This is a capital recovery economic calculation

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

Where:

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

\[
DF = \frac{i(1+i)^n}{(1+i)^n - 1}
\]
**Economic Replacement Threshold**

Example: Payback calculations for new rings and rod replacement

CR = $1,620 for rings + $9,450 for rod = $11,070
H = 8,000 hours per year
GP = $7/Mcf

One year payback

\[ ER = \frac{11,070 \times 1.1 \times 1,000}{8,000 \times 7} \]

\[ = 217 \text{ scf per hour} \]

**Is Rod Packing Replacement Profitable?**

Replace packing when leak reduction expected will pay back cost

“leak reduction expected” is the difference between current leak rate and leak rate with new rings

<table>
<thead>
<tr>
<th>Leak Reduction Expected (cf/hour)</th>
<th>Payback (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>61</td>
<td>6</td>
</tr>
<tr>
<td>32</td>
<td>12</td>
</tr>
<tr>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>12</td>
<td>36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leak Reduction Expected (cf/hour)</th>
<th>Payback (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>415</td>
<td>6</td>
</tr>
<tr>
<td>217</td>
<td>12</td>
</tr>
<tr>
<td>114</td>
<td>24</td>
</tr>
<tr>
<td>75</td>
<td>36</td>
</tr>
</tbody>
</table>

Based on 10% interest rate

Mcf = thousand cubic feet
Industry Experience – Northern Natural Gas

- Monitored emission at two locations
  - Unit A leakage as high as 301 liters/min (640 cf/hour)
  - Unit B leakage as high as 105 liters/min (220 cf/hour)
- Installed Low Emission Packing (LEP)
  - Testing is still in progress
  - After 3 months, leak rate shows zero leakage increase

---

Northern Natural Gas - Leakage Rates

![Graph showing leakage rates from 1997 to 2005.](image)

- Unit A leakage rates:
  - Peak at 600 liters/min (1200 cf/hour)
  - Drop to zero after LEP installation.
- Unit B leakage rates:
  - Peak at 100 liters/min (200 cf/hour)
  - Drop to zero after LEP installation.

---

28

29
Northern Natural Gas Packing Leakage Economic Replacement Point

- Approximate packing replacement cost is $3,000 per compressor rod (parts/labor)
- Assuming gas at $7/Mcf:
  1 cubic foot/minute = 28.3 liters/minute
  - 50 liters/minute/28.316 = 1.8 scf/minute
  - 1.8 x 60 minutes/hour = 108 scf/hr
  - 108 x 24/1000 = 2.6 Mcf/day
  - 2.6 x 365 days = 950 Mcf/year
  - 950 x $7/Mcf = $6,650 per year leakage
- This replacement pays back in <6 months

Low Emission Packing

- Low emission packing (LEP) overcomes low pressure to prevent leakage
- 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

Orientation in Cup

LEP: Low Emissions Packing
Orientation of P303 Rings
Reasons to Use LEP

- Upgrade is inexpensive
- Significant reduction of greenhouse gas are major benefit
- Refining, petrochemical and air separation plants have used this design for many years to minimize fugitive emissions
- With gas at $7/Mcf, packing case leakage should be identified and fixed.

Discussion

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