Centrifugal Compressor Wet Seals
Seal Oil De-gassing & Control

Natural Gas Star Annual Workshop; Denver, Colorado; April 2012
Reid Smith BP,
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
- Wet seals leak little gas at the seal face
- Most emissions are from seal oil degassing
- Seal oil degassing may vent 40 to 200 scf/minute
- One Natural Gas STAR Partner reported emissions as high as 75,000 scf/day

Source: PEMEX
Traditional Solution: Retrofitting/Installing Dry Seals

Dry seals:
• 0.4 to 2.8 scf/min leak rate
• Significantly less than emissions from wet seals
Very cost-effective option for new compressors
Significant capital costs and downtime for retrofitting compressors

See *Lessons Learned* for more info¹

Seal-oil degassing and vapor recovery is a more cost effective retrofit with less downtime and roughly equivalent emissions

Dry seals keep gas from escaping while rotating with the shaft

Tandem dry seals

Source: PEMEX
Background of North Slope Study

- Natural Gas STAR learned of anecdotal information on this potential mitigation opportunity a few years back
  - Developed a theoretical example and presented to Natural Gas STAR Partners at workshops and in the Spring 2009 Newsletter

- In taking measurements, BP identified wet seal gas recovery systems on centrifugal compressors at its North Slope facilities
  - BP’s initial results showed recovery of >99% of seal oil gas that would be otherwise vented to atmosphere from degassing tank

- Led to BP and Natural Gas STAR collaboration on detailed measurement study of alternative wet seal capture mitigation opportunity
  - Recovery system that separates gas from the sour seal oil before being sent to the degassing tank
  - Recovered gas sent to various outlets: flare purge, low pressure fuel, turbine fuel ~273 psig (18.6 Bar), compressor suction
  - System leads to lower emissions from degassing tank vent (more details on following slides)
Overview of North Slope Operations

Prudhoe Bay

Six Flow Stations

How we get the oil from the ground to the Trans-Alaska pipeline.

Crude oil at Prudhoe Bay is located in the Sadlerochit zone, a sandstone formation at approximately 9,000 feet below the earth’s surface. Pressure from the formation pushes the crude up a well to the surface where a wellhead controls the flow of crude. Wellheads are located on gravel drill sites and are covered by a well house for worker and equipment protection against the harsh arctic environment. From here the crude flows through the manifold building, also located on the drill site, where oil/gas/water ratio is determined. Crude then travels to a processing center and is separated into oil, gas and water. Natural gas is sent to the gas handling facilities for reinjection back into the field. Produced water is sent back to the drill sites and reinjected into the formation to help in the oil recovery. Oil continues its journey to Alyeska’s Pump Station 1 to begin its 800 mile trip to Valdez.
Overview of North Slope Operations

~100 Centrifugal Compressors
All but a few with Wet Seals
All Wet Seal machines equipped with recovery system
Pressures: 3 psi suction => 4,700 psi discharge
Fluids range from propane through to wet gas to dry gas

Prudhoe Bay process flow and volumes
Central Gas Facility (CGF)

- World’s largest gas processing plant (max feed of ~ 8bcf/day)
- Processes all gas from Prudhoe Bay gathering & boosting stations (except local fuel)
- Products:
  - Residue gas
  - Natural gas liquids (blended with oil and delivered to TAPS)
  - Miscible injectant (used for EOR purposes)
- 11 compressors (totaling over 500,000 HP)
  - Three boosters
  - Two refrigerant
  - Two MI
  - Four tandems
- Seal oil vapor recovery lines routed to flare purge
Central Compressor Plant (CCP)

- World’s largest compressor station (~8bcf/day capacity)
- Receives residue gas from CGF, compresses to higher pressures, and sends to gas injection well-pads (~7.1 BCF/day at 3,600 to 4,000 psig)
- 15 compressors (totaling 537,000 HP)
  - Nine low pressure (1st stage) compressors in parallel
  - Four high pressure (2nd stage) compressors in parallel
  - Two tandem compressors (1st and 2nd stages) in parallel
- Seal oil vapor recovery lines routed to fuel gas (for compressor turbines, heaters, and blanket gas)
Sour Seal Oil Vapor Recovery System

**Diagram:**
- Seal Housing
- Seal Oil Inlet
- Motor and Shaft Bearing Side “Outboard”
- “Outboard” Labyrinth
- Seal Oil (Uncontaminated)
- Seal Oil (Contaminated with Gas)
- Spinning Shaft
- Seal Oil (Contaminated with Gas)
- Critical Orifice
- Atmospheric seal oil degassing drum
- Less gas vented to atmosphere
- Seal oil discharge pressure = ~1500 psi
- New fuel pressure seal oil degassing drum and demister (“sour seal oil trap”)
- Seal oil circulation pump

**Options:**
- FLARE PURGE
  - ~27 psi
  - ~275 psi
- COMPARATOR
  - ~65 psi
- Boiler
- Compressor turbine fuel
  - ~65 psi

**Notes:**
- New equipment in red

**Text:**
- Pressure levels:
  - ~27 psi
  - ~65 psi
  - ~275 psi
- System components:
  - Compressor suction/recycle
  - Varied

**System Details:**
- Seal oil discharge pressure = ~1500 psi
- New fuel pressure seal oil degassing drum and demister (“sour seal oil trap”)
- Less gas vented to atmosphere

*Note: New equipment in red*
Sour Seal Oil Vapor Recovery System: CCP

Restrictive Orifice 1/16”
Seal Oil Degassing Separators
Seal Oil Degassing Separators
Seal Oil Degassing Separator/System

Restrictive Orifice
(note frost from expansion cooling)
Seal Oil Degassing Separators
Early Results: BP Measurements of CCP

- Table shows initial measurements taken by BP from a low- and high-pressure compressor at CCP before study
- Used nitrogen as “tracer gas” to calculate methane and total hydrocarbon flow-rates from vents
- Recovered Gas: 0.92 MMSCFD LP; 3.7 MMSCFD HP Turbine Fuel

<table>
<thead>
<tr>
<th></th>
<th>High-Pressure Compressor</th>
<th>Low-Pressure Compressor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen Purge Rate (SCF/Hr)</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>Vent Analysis (mole%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>43.846</td>
<td>86.734</td>
</tr>
<tr>
<td>Methane</td>
<td>37.872</td>
<td>6.93</td>
</tr>
<tr>
<td>Total Hydrocarbon + CO2</td>
<td>56.1540</td>
<td>13.2660</td>
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<tr>
<td>Total Methane Vent Flow (SCFM)</td>
<td>0.4751</td>
<td>0.0333</td>
</tr>
<tr>
<td>Total Vent Gas Flow (SCFM)</td>
<td>0.7044</td>
<td>0.0637</td>
</tr>
<tr>
<td>Number of Seals</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Total Methane Vent Flow (SCFM/Seal)</td>
<td>0.2375</td>
<td>0.0166</td>
</tr>
<tr>
<td>Total Vent Gas Flow (SCFM/Seal)</td>
<td>0.3522</td>
<td>0.0319</td>
</tr>
<tr>
<td>&quot;Average&quot; Total Gas/Seal (Including Recovered) (SCFM)</td>
<td>108</td>
<td>108</td>
</tr>
<tr>
<td>Control Percentage</td>
<td>0.997</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Preliminary results: Velocity Measurements

- Table shows vane anemometer measurements taken prior to and during the study.
- Full results of study are not yet final, but initial results from CCP measurements show generally consistent with BP’s results from before the study.

### CCP Velocity Readings - During Study

<table>
<thead>
<tr>
<th>Facility</th>
<th>Compressor Tag</th>
<th>Compressor description</th>
<th># of Seals per Tank</th>
<th>Vent size m/s</th>
<th>1 Min Mean</th>
<th>1 Min Mean</th>
<th>1 Min Mean</th>
<th>Vent Area #2</th>
<th>rpm/30m</th>
<th>N2 Purge scf/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCP</td>
<td>K-18-1801</td>
<td>1st Stage Injection comp Degassing Tank Vent</td>
<td>2 2</td>
<td>0.36 0.38 0.28 0.022</td>
<td>66.9 1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CCP</td>
<td>K-18-1809</td>
<td>2nd Stage Injection comp Degassing Tank Vent</td>
<td>2 2</td>
<td>0.42 0.4 0.2 0.022</td>
<td>66.9 1.5</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Seal Oil Reservoir Vent</td>
<td>4 4</td>
<td>0.6 0.57 0.81 0.087</td>
<td>129.9 11.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

### CCP Velocity Readings - Prior to Study

| END      | K-18-1801      | 1st Stage Injection comp Degassing Tank Vent | 2 2 | 0.36 0.38 0.28 0.022 | 66.9 1.5 |
| END      | K-18-1809      | 2nd Stage Injection comp Degassing Tank Vent | 2 2 | 0.42 0.4 0.2 0.022 | 66.9 1.5 |

### Additional Data

- Table includes velocities for various facilities, including compressors and vents, with measurements taken during and before the study.
- Results show generally consistent trends with previous studies.
CCP Compressor Vent Measurement
Close-up
FLIR Camera Verification
Applicability & Benefits

- Based on the results, a sour seal oil vapor recovery system could prove to be an economic alternative to dry seal retrofits on centrifugal compressors
  - Dry seals on new compressors are now more prevalent in industry—typically cheaper than wet seals
  - Dry seal retrofits on older compressors very high in cost; ~$250,000 to $1 million per compressor
  - Sour seal oil vapor recovery system on wet seals compressors much lower in capital cost, requires short duration compressor shutdown or interruption in gas service
- Recovery projects can provide companies with a way to both reduce methane emissions and utilize recovered gas cost-effectively
Applicability/Benefits

Investment includes cost of:
- Intermediate degassing drum ("sour seal oil trap")
- New piping
- Gas demister/filter
- Pressure regulator for fuel gas line

Project summary:
- Less expensive capital costs compared to dry seal retrofit
- Prevents most seal oil gas emissions from venting to atmosphere while also improving site efficiency
- Positive cash flow after less than a month

### PROJECT SUMMARY: CAPTURE AND USE OF SEAL OIL DEGASSING EMISSIONS

| Operating Requirements | Centrifugal compressor with seal oil system
|                        | Nearby use for fuel gas or recycle
|                        | New intermediate pressure flash drum, fuel filter, pressure regulator

<table>
<thead>
<tr>
<th>Capital &amp; Installation Costs</th>
<th>$22,000¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Labor &amp; Maintenance Costs</td>
<td>Minimal</td>
</tr>
<tr>
<td>Gas saved</td>
<td>~100 MMSCF/Year (2 seals @ 108 scf/min each)</td>
</tr>
<tr>
<td>Gas Price per mscf</td>
<td>$2.5</td>
</tr>
<tr>
<td>Value of Gas Saved</td>
<td>$250,000</td>
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<tr>
<td>Payback Period in Months</td>
<td>1</td>
</tr>
</tbody>
</table>

¹Assuming a typical seal oil flow rate of 14.20 liters/minute (3.75 gallons/minute)
Conclusions and Next Steps

- Preliminary results are promising and indicate that sour seal oil vapor recovery from centrifugal compressors can be a viable project option for companies.
- BP and Natural Gas STAR currently analyzing data obtained during study.
- BP and Natural Gas STAR will continue to collaborate on this study to fully characterize the seal oil vapor recovery system seen on the North Slope.
- Team to publish more detailed results of study in a future article.
Contact Information

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