Natural Gas STAR
Production Technology Transfer Workshop

“Centrifugal Compressor Wet Seal”
“Seal Oil Degassing & Recovery”

Reid Smith
Senior Climate Advisor - BP
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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/ minute leak rate
  • Significantly less than wet seals

• **Very cost-effective option for new compressors**

• **Significant capital costs and downtime for retrofitting compressors**
  • See *Lessons Learned* for more info

• **Alternative exists for more cost-effective seal oil degassing and vapor recovery retrofit with less downtime**

  *Dry seals keep gas from escaping while rotating with the shaft*

Source: PEMEX
Alternative Solution – Seal-oil/Gas Separation and Recovery/Use

• Simple process of separating seal-oil and entrained gas with the gas routed to recovery and/or use.
  – Recovery system that separates gas from the exiting seal-oil before routing to the degassing tank
  – Recovered gas sent to various outlets: flare purge, low pressure fuel, turbine fuel ~273 psig (18.6 Bar), compressor suction
  – Systems lead to lower emissions from degassing tank vent (more details on following slides)

• BP has wet seal gas recovery systems on ~ 100 centrifugal compressors at its North Slope facilities
  – BP’s initial results show recovery of >99% of seal oil gas that would be otherwise vented to atmosphere from degassing tank
  – BP and Natural Gas STAR collaborated on a detailed study of the alternative wet seal emission mitigation opportunity.
BP’s North Slope Experience

~100 Wet Seal Centrifugal Compressors - all equipped with separation system
Original design and installation
Pressures: 3 psi suction => 4,700 psi discharge
Size ranges from ~40 MW to ~2 MW turbine drivers
Fluids range from propane through wet gas to dry gas
Zero failures in 30+ years of seal operation
Central Gas Facility (CGF)

- **World’s largest gas processing plant (max feed of 246 MMcm/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 to flare purge**
Central Compressor Plant (CCP)

• World’s largest compressor station (~238 MMcm/day capacity)

• Receives residue gas from CGF, compresses to higher pressures, and sends to gas injection wellpads (~200 MMcm/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 sent to flare or fuel gas (for compressor turbines, heaters, and blanket gas)
Sour Seal Oil Vapor Recovery System

*Note: New equipment in red*

Seal Oil Inlet

Motor and Shaft Bearing Side “Outboard”

“Outboard” Labyrinth

Seal Oil Inlet

Seal Housing

Process Gas Leaks Through “Inboard” Labyrinth Seal

Compressor Side “Inboard”

Spinning Shaft

Seal Oil (Uncontaminated)

Seal Oil (Contaminated with Gas)

Seal Oil discharge pressure = 96.3 atm

New fuel pressure seal oil degassing drum and demister (“sour seal oil trap”)

Atmospheric seal oil degassing drum

Less gas vented to atmosphere

Seal oil circulation pump

Compressor

Boiler

18.0 atm

4.4 atm

1.8 atm

4 OPTIONS

FLARE

Low pressure fuel gas

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Seal-Oil/Gas Separation and Recovery System: CCP

T/C 1801 SEAL OIL

Suction Pressure 543.5 PSI

Reference Gas

High Level
L= 77.0 %
Low Level
LO L0 LEY SO

Diff. Press.
5.5 PSI
S.O. Low DP Trip

Low Pressure
S.O. Supply 560.9 PSI

Sweet S.O. Hi Temp
147.9 Deg
Sweet S.O. Inboard Drain

Sour Seal Oil Vapors

Sour S.O. Drains

Gas

SO TRAPS

SO DEGAS TANK HI TEMP

N2 Supply

210.1 Deg

Degassing Tank

220.3 Deg

SO RESERVOIR HI LEVEL

HI TEMP

SO RESERVOIR HI LEVEL

Cooling Supply

Cooling Return

Seal Oil Cooler

Seal Oil Filter

S.O. Filter Hi DP

Seal Oil Reservoir

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Seal Oil Degassing Separators
Seal Oil Degassing Separator/System

Restrictive Orifice (note frost from expansion cooling)
Early Results: BP Measurements at 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>
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<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>
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<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>
</tr>
<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>“Average&quot; Total Gas/Seal (Including Recovered) (SCFM)</td>
<td>108</td>
<td>108</td>
</tr>
<tr>
<td>Control Effectiveness</td>
<td>0.997</td>
<td>1.000</td>
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CCP Compressor Vent Measurement
FLIR Camera Verification
Benefits

• **Benefits of approach**
  – Simple, broadly flexible, and reliable
  – Less expensive capital costs compared to dry seal retrofit ($250,000 - $1 million – dry seal retrofit)
  – Less down-time compared to dry seal retrofit
  – Eliminates most emissions & recovers gas for use/sales
  – Positive cash flow after less than a month

• **Investment includes cost of:**
  – Intermediate degassing drum (“sour seal oil trap”)
  – New piping
  – Gas demister/filter
  – Pressure regulator for fuel gas line

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

<table>
<thead>
<tr>
<th>Operating Requirements</th>
<th>Centrifugal compressor with seal oil system</th>
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<tbody>
<tr>
<td></td>
<td>Nearby use for fuel gas or recycle</td>
</tr>
<tr>
<td></td>
<td>New intermediate pressure flash drum, fuel filter, pressure regulator</td>
</tr>
<tr>
<td>Capital &amp; Installation Costs</td>
<td>$22,000¹</td>
</tr>
<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>
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<tr>
<td>Value of Gas Saved</td>
<td>$250,000</td>
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<td>Payback Period in Months</td>
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¹Assuming a typical seal oil flow rate of 14.20 liters/minute (3.75 gallons/minute) (Source: EPA)
CONCLUSIONS

• Centrifugal compressor oil film (wet) seals have been utilized since the early 1970’s

• These seal systems, including the degassing function, when designed, operated and monitored properly are an effective sealing system and greatly minimize emissions

• Wet seals with degassing systems installed originally with compressors can perform effectively with very low emissions and high reliability

• Retrofit degassing systems should be able to meet the same low emissions and high reliability operation