Centrifugal Compressor Wet Seals
Seal Oil De-gassing & Control

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Reid Smith - BP,
Kevin Ritz BGE
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
• **Baltimore Gas & Electric Company is the nations first Gas utility in the U.S. established in 1816**
  • Serves approximately 650,000 natural gas customers
  • 6500 miles of distribution lines
  • 164 miles of transmission lines
  • Operates three peak shaving facilities

• **BGE’s Spring Gardens LNG Facility**
  • Original Construction in 1971
  • Storage - (1 BCF/12 million gallons)
  • Vaporization - 312,000 dth/day
  • Liquefaction - (2) Systems
    (1) Open Expander Cycle
    (1) Mixed Refrigerant Liquefier (MRL)
    (1) MRL compressor originally fitted with wet cone seals with degassing system.
  * Unit in service 20 years without seal failure!
North American "Natural Gas Energy" Grid

From wellhead to burner tip, this graphic shows the pieces and parts of a natural gas energy grid. The sections in orange show a typical LNG peak shaving plant location.
• **US LNG Facilities**
  
  • 121 LNG facilities nationwide,
  • 11 Base Load LNG terminals, Most originally designed as import, recent filings to construct/operate liquefaction and export

• 109 LNG peak shaving facilities, approximately, 50% are peak shaving facilities with storage liquefaction, and vaporization systems

• LNG peak shaving facilities are typically owned/operated by Local Distribution Companies that utilize the facilities to meet peak natural gas demand periods, typically the coldest days of the year.
**Simplified LNG Liquefaction Process**

- Booster Compressor
- Cold Box
- LNG Storage Tank
- Heat Exchangers
- Refrigerant Compressor
- Pretreatment CO2 & H2O Removal

**MRL Refrigeration**

**MRL Constituents**
- 44% Methane
- 16% Ethane
- 18% Propane
- 22% Butane
The Problem

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 typically vents methane to the atmosphere
  - Seal oil degassing may vent 40 to 200 scf/minute

Traditional Solution: Retrofitting/Installing Dry Seals

- Mechanical seal that keeps gas from escaping while rotating with the shaft.
- 0.4 to 2.8 scf/min leak rate – significantly less than from wet seals
- Cost-effective option for new compressors
- Significant capital costs and downtime for retrofitting compressors
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.

- BGE has the similar system on a centrifugal refrigerant compressor at its liquefied natural gas (LNG) peak shaving facility
BGE’s MRL Compressor Cone Seal System

Principle of Seal Operation

- Tapered cone seal sleeves are fitted to the compressor shaft, rotate at 11,200 RPM
- Spring loaded, non-rotating, mating inner seal rings move axially are located within the seal housings
- Springs between the non-rotating inner and outer seal rings keep seal is open (separated) when the compressor casing is not pressurized (isolated from refrigeration system by suction and discharge valves
- Pressurizing the compressor casing moves the non-rotating inner seal ring, axially against the cone seal sleeve fixed on the shaft. This lock-up minimizes gas leakage as the compressor is initially pressurized during startup
- Seal oil flow is established and fills the elevated seal oil tank, tank level is controlled by flow across seals and the seal oil tank level controller
- Reference gas is established and equalizes the gas pressure between the seal cavity and the seal tank vapor space
- Seal oil from the elevated seal tank creates a differential pressure of 6-7 psig between the seal oil and process gas in the seal cavity, overcomes the forces on the non-rotating inner seal rings separating inner seal rings from metal to metal contact with the rotating cone seal sleeve (0.004 - 0.0045) with seal oil
- The oil between the rotating cone seal sleeve and non-rotating inner and outer seal rings prevents the MRL refrigerant gases form escaping the compressor to the atmosphere during operation.
Compressor case depressurized, no seal oil

Seal Faces Open

 SEAL RING OUTER

 SEAL RING INNER

 SEAL RING RETAINER

 CONE SEAL SLEEVE
Compressor case pressurized, no seal oil

Process Gas

Seal faces closed

Seal Ring Retainer

Seal Ring Inner

Seal Ring Outer

Cone Seal Sleeve
Compressor case pressurized, seal oil established. Operating conditions!

Seal Oil to outboard drain. No gases entrained

Seal Oil to inboard seal oil drainer. Entrained gases

Seal Faces Open

CONE SEAL SLEEVE

SEAL RING OUTER

SEAL RING INNER

SEAL RING RETAINER

Process Gas

Seal Oil
Centrifugal Compressor Rotating Element & Cone Seal Assembly

8 Stages
BP’s Seal-Oil/Gas Separation and Recovery System: CCP (Typical of BGE System)

Restrictive Orifice 1/16”

~ 275 psi
To turbine fuel system
Compressor is an 8 Stage centrifugal compressor
Compressor operates at 11,200 RPM
Equipped with oil film cone shaft sealing system including degasification
Seal Oil Tank
Approximate Elevation = 20'

Seal Oil to Seals

Seal Oil from Supply
Outer Seal (sweet oil) Oil Drain

Seal Oil Supply – 10-11 gpm

Inner Seal (sour) Oil Drain to Drainer

Bearing Oil Drain

Critical Orifice

Seal Oil Drainer
Seal Oil Degassing Separators
C-101 Seal Oil System

- With both seal oil drainer outlets closed, the sight glasses on both drainers area observed for a level rise.
- A rise in the drainer levels ensures both cone seals are flowing oil and that they are no longer in metal to metal contact between the inner seal ring with the mating cone seal sleeve on the rotating compressor shaft. Open drainer outlet valves.
- The seal oil that did not come into contact with the process gas (sweet oil) flows through the outboard seal drain returning directly to the main seal oil sump.
- The seal oil flows that across the seals coming into contact with the process gas (sour oil), drains through the inboard seal drain to the seal oil drainers.
- The oil from the seals to the drainers has dissolved/infused process gas entrained.
- The gas in the oil is released in the drainer and the process gas is drawn off the drainer through the “Critical Orifice” and returns to the compressor suction after passing through a demister / coalescing filter.
- The degassed seal oil in the drainer then returns to the main oil sump in the compressor base.
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>
</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>
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<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>
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<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>
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<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” 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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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

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

| Capital & Installation Costs | $22,000¹ |
| Annual Labor & Maintenance Costs | Minimal |
| Gas saved | ~100 MMSCF/Year (2 seals @ 108 scf/min each) |
| Gas Price per mscf | $2.5 | $3.0 | $3.5 |
| Value of Gas Saved | $250,000 | $300,000 | $350,000 |
| Payback Period in Months | 1 | <1 | <1 |

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 fugitive 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