Reliable Compression of Sour and other Process Gases – Special Rolling Bearings for Oil-flooded Screw Compressors

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Content

This case study on oil-flooded screw compressors briefly covers:

- Basic designs of oil-flooded screw compressors
- Process layouts
- Failure modes for conventional bearings seeing:
  - Water condensing Sour (H₂S) and Acid (CO₂) gases
  - Water condensing Hydrogen-rich process gases.
- “Sour gas rolling bearings” consisting of:
  - Super-tough stainless steel bearing rings
  - Bearing grade silicon nitride ceramic rolling elements
  - Glass fiber reinforced polymeric PEEK cages
- A “service-life diagram” vs. H₂S and CO₂ mol%
Oil-flooded Machines

Twin screw compressor:
- One main rotor (male)
- One large gate rotor (female)
- 2 radial bearings (similar size) on each rotor
- 1-4 thrust bearings (similar sizes) on each rotor

Single screw compressor:
- One main rotor (female)
- Two small gate-rotors (male)
- 1 radial roller bearing on each rotor
- 2 thrust ball bearings (same sizes) on each rotor (combined thrust and radial loads)
Twin Screw Compressors – Bearing Arrangements

CRB – Cylindrical Roller Bearing (pure radial loads)
FPACBB – Four Point Angular Contact Ball Bearing (pure axial loads, two directions)
SRACBB – Single Row Angular Contact Ball Bearing (pure axial loads, one direction)

| Suction: CRB | Discharge: CRB + FPACBB | Alternative: Journal (radial) + 2 x SRACBB |

All bearings are working under suction pressure.
Oil Systems for Process Gases

The oil systems for the compressors are designed to:

- **Lubricate:**
  - Bearings;
  - Face seals on the input shaft;
  - Screw-to-screw contact; and
  - Input gears, if present and incorporated into the compressor

- **Cool the compression process;**

- **Seal:**
  - Screw-to-screw contact; and
  - Screw-to-wall gaps.

⇒ The process gas is in contact with the re-circulated oil.
⇒ The oil pickup contamination from the process gas
## Bearings & Materials

<table>
<thead>
<tr>
<th>Rolling bearings</th>
<th>Steel rings</th>
<th>Rolling elements</th>
<th>Cage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Common bearing steel *</td>
<td>Common bearing steel *</td>
<td>Steel or brass</td>
</tr>
<tr>
<td>Sour gas</td>
<td>Super-tough stainless bearing steel **</td>
<td>Bearing grade silicon nitride ceramics ***</td>
<td>Glass fiber reinforced PEEK or Single piece brass</td>
</tr>
</tbody>
</table>

* AISI 52100 type; ** AMS 5898 & SKF hardening specification; ***ASTM F2094M - 11 Standard Specification for Silicon Nitride Bearing Balls plus SKF specifications
Process Flow: Oil-flooded Twin Screw Compressor

- Flare => SO₂
- Vacuum Off Gas:
  - H₂S 30 – 40 mol%
  - CO₂ 35 mol%
  - H₂O Fully saturated
  - Mole weight = 36
- Over Head Seal Drum
- Gas cooler
- Suction Scrubber
- Screw Comp.
- Oil Filter
- Oil Separator 150 psig (1030 kPa)
- Oil Cooler
- Lube Oil supply
- Recovered Gas – Out
- Lube oil & gas

- Drain
- Sour Water Stripper
- Refinery off-gas service (case #1)
- In service since 2004 with sour gas bearings.

Screw Comp. Oil
Cooler
Oil
Filter
Bearings
Screws
15 psig (100 kPa)
Hydrogen recycle single screw compressor with SKF sour gas bearing. In a diesel sulfur reduction process.

Inlet hydrogen-rich, recycled gas 225 psig (1760 kPa) & 130°F (54°C)

Discharge 420 psig (2900 kPa) & 190°F (88°C)

Process Flow: Oil-flooded Single Screw Compressor

- Refinery diesel sulfur reduction process of a distillate unifier (case #3).
- In service since 2006 with sour gas bearings.
## Gas Conditions vs. Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>#</th>
<th>VRU/Off-gas</th>
<th>Gas well boosting</th>
<th>Hydrogen-rich service</th>
<th>Recip boosting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>MW&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>g mol</td>
<td>36</td>
<td>20</td>
<td>9</td>
<td>41</td>
</tr>
<tr>
<td>k&lt;sub&gt;suction&lt;/sub&gt;</td>
<td>*k (*k)</td>
<td>0.031 (18)</td>
<td>0.052 (30)</td>
<td>0.23 (132)</td>
<td>–</td>
</tr>
<tr>
<td>CO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>mol%</td>
<td>35%</td>
<td>5.5%</td>
<td>0.4%</td>
<td>70%</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;S</td>
<td>mol%</td>
<td>40%</td>
<td>5.5%</td>
<td>0.01%</td>
<td>30%</td>
</tr>
<tr>
<td>H&lt;sub&gt;2&lt;/sub&gt;</td>
<td>mol%</td>
<td>n/a</td>
<td>n/a</td>
<td>65%</td>
<td>–</td>
</tr>
<tr>
<td>P&lt;sub&gt;suction (abs)&lt;/sub&gt;</td>
<td>psi (kPa)</td>
<td>15 (100)</td>
<td>42 (288)</td>
<td>270 (1860)</td>
<td>–</td>
</tr>
<tr>
<td>P&lt;sub&gt;H2S, suct (abs)&lt;/sub&gt;</td>
<td>psi (kPa)</td>
<td>6 (40)</td>
<td>2.3 (16)</td>
<td>0.03 (0.2)</td>
<td>–</td>
</tr>
<tr>
<td>In situ pH&lt;sub&gt;suct&lt;/sub&gt;</td>
<td>–</td>
<td>4.0</td>
<td>4.1</td>
<td>4.5</td>
<td>–</td>
</tr>
</tbody>
</table>

**VRU** = Vapor Recovery Unit; **MW<sub>avg</sub>** = Molecular weight of compressed gas; (l) = Estimation, Clarification or ISO units; **P<sub>suction</sub>** = pressures of gas at suction; **P<sub>H2S, suct</sub>** = partial pressure of H<sub>2</sub>S at suction and discharge; **In situ pH** = estimation by using the combined partial pressure of H<sub>2</sub>S and CO<sub>2</sub> according to ISO 15156-2:2009

**Thermal conductivity:** *k = Btu ft/(hr ft<sup>2</sup> °F); (k*) = mW/mK
## Mechanical and Process Condition vs. Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>#</th>
<th>1 VRU/Off-gas</th>
<th>2 Gas well boosting</th>
<th>3 Hydrogen-rich service</th>
<th>4 Recip boosting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>–</td>
<td>Twin</td>
<td>Twin</td>
<td>Single</td>
<td>Twin</td>
</tr>
<tr>
<td><strong>Rotor size, Ø</strong></td>
<td>mm</td>
<td>233</td>
<td>193</td>
<td>350</td>
<td>355</td>
</tr>
<tr>
<td><strong>rpm</strong></td>
<td>rpm</td>
<td>3600</td>
<td>1800</td>
<td>3600</td>
<td>–</td>
</tr>
<tr>
<td><strong>$T_{suction}$</strong></td>
<td>°F (°C)</td>
<td>77 (25)</td>
<td>–</td>
<td>129 (54)</td>
<td>–</td>
</tr>
<tr>
<td><strong>$T_{discharge}$</strong></td>
<td>°F (°C)</td>
<td>240 (115)</td>
<td>200 (94)</td>
<td>190 (88)</td>
<td>–</td>
</tr>
<tr>
<td><strong>$P_{suction} (abs)$</strong></td>
<td>psi (kPa)</td>
<td>15 (100)</td>
<td>42 (288)</td>
<td>270 (1860)</td>
<td>–</td>
</tr>
<tr>
<td><strong>$P_{discharge} (abs)$</strong></td>
<td>psi (kPa)</td>
<td>150 (1030)</td>
<td>130 (897)</td>
<td>435 (3000)</td>
<td>–</td>
</tr>
<tr>
<td><strong>DewP_{discharge}</strong></td>
<td>°F (°C)</td>
<td>– *</td>
<td>–</td>
<td>149 (65)</td>
<td>– *</td>
</tr>
</tbody>
</table>

* $\text{H}_2\text{S} + \text{CO}_2 > 40 \text{ mol\%}$, dew point difficult to define; $\text{DewP}_{discharge} = \text{Dew point at discharge conditions}$
Sour Gas – Failure Modes of Conventional Bearings

Ring spalling of conventional ball bearing rings by stress cracking from wet sour gas in combination with standstill periods

Typical sour gas failure by stress cracking, causing splitting of conventional steel balls. Secondary failure of brittle polymeric PPS cage.
Sour Gas – The Failure Process of Splitting Steel Balls

Bearing balls from the thrust bearing of 355 mm (13.97 inches) oil-flooded twin screw compressor under sour gas conditions.

**Left:** Ball with initiation groove around the equatorial running line.

**Middle:** A ball after being split in half under running.

**Right:** Ball that has seen rotation and been running in three tracks, and thus in the end failed by a “Pacman failure”
Hydrogen-rich Gas – Failure Modes of Thrust Bearings

Conventional thrust bearing for an oil-flooded single screw (350 mm / 13.78 inches) compressor.

- Frosted raceways (Poor lubrication)
- Flaked shoulder (Hydrogen Stress Cracking)
## Service-life vs. Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>#</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
<td>VRU/Off-gas²</td>
<td>Gas well boosting</td>
<td>Hydrogen-rich service</td>
</tr>
<tr>
<td>Type</td>
<td>–</td>
<td>Twin</td>
<td>Twin</td>
<td>Single</td>
</tr>
<tr>
<td>Conventional</td>
<td>Years</td>
<td>&lt; 0.5</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Sour gas</td>
<td>Years</td>
<td>~ 3</td>
<td>&gt; 5</td>
<td>&gt;3 (?)</td>
</tr>
<tr>
<td>$p_{\text{H}_2\text{S}, \text{suction}}$ (abs)</td>
<td>psi (kPa)</td>
<td>6 (40)</td>
<td>2.3 (16)</td>
<td>0.03 (0.2)</td>
</tr>
<tr>
<td>$\text{In situ pH}_{\text{suct}}$</td>
<td>–</td>
<td>4.0</td>
<td>4.1</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Sour Gas Bearings

High resistance to:
- Sulfide Stress Cracking
- Hydrogen Stress Cracking
- Poor lubrication (low lube oil viscosity)
- General corrosion
- Pitting corrosion
- Standstill corrosion

Inert to:
- Electric arcing (e.g. VFDs)

Good performance against:
- Particle contamination
Sulfuric Stress Cracking (SSC) Map

NACE MR0175 present SSC map with regions of severity from 0 – no attack, to 3 – severe region.

**The diagram plot:**

- **X-axis** – \( \log \text{pH}_2\text{S} \) Partial \( \text{H}_2\text{S} \) pressure
- **Y-axis** – *in situ* pH i.e. pH at service given by the combined partial pressures of \( \text{H}_2\text{S} \) and \( \text{CO}_2 \).

- \( p_i \) (partial pressure of gas i) = \( y_i \) (mol fraction of gas i) x \( P_{\text{suction}} \) (total pressure at suction)

- \( \text{kPa} = \text{psi} \times 6.895 \)

- *in situ* \( \text{pH}_{20\text{C}} = 4.9 - 0.5 \log(p_{\text{H}_2\text{S}} + p_{\text{CO}_2}) \)
Service-life Diagram for Sour Gas Bearings under SSC

Based on NACE/ISO SSC diagram with working points for compressor cases #1 to 3
References


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Mickalec, J.R., ‘Bringing to light lube oil moisture in hydrogen cooled generators”, http://www.machinerylubrication.com/Articles/Print/132