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 (H_2S) and Acid (CO_2) 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. H_2S and CO_2 mol%

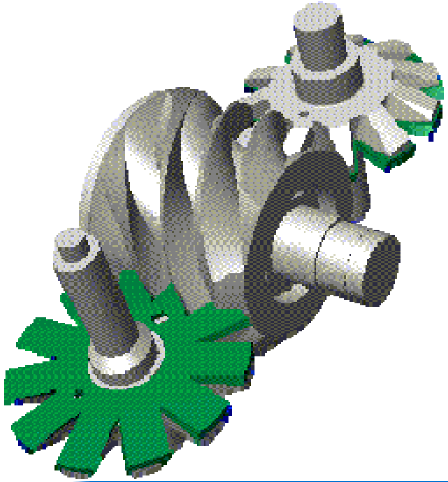
Oil-flooded Machines

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

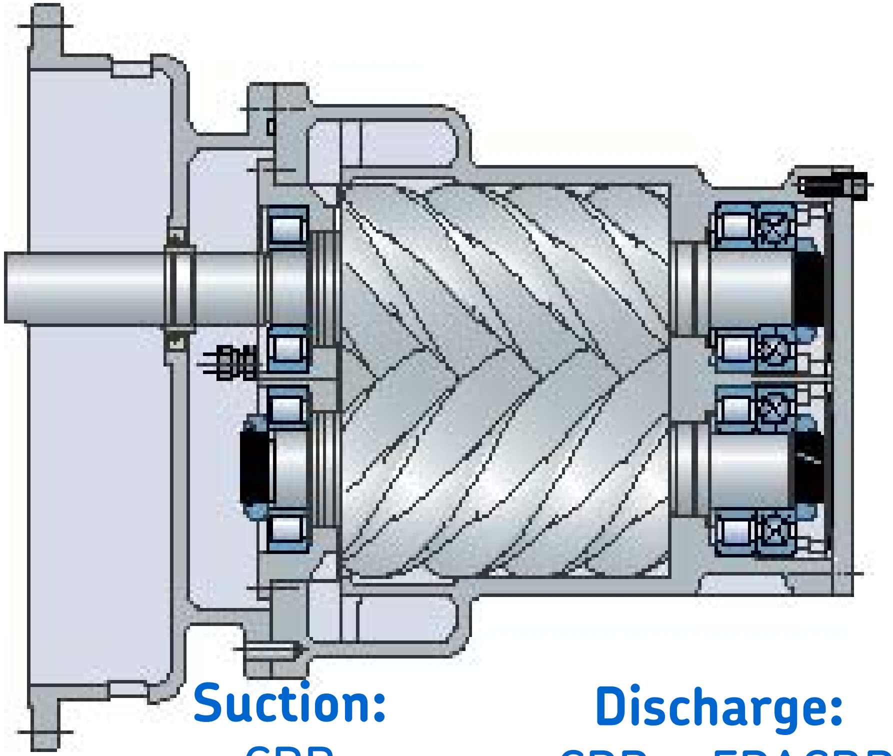
Single screw compressor:

- 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)



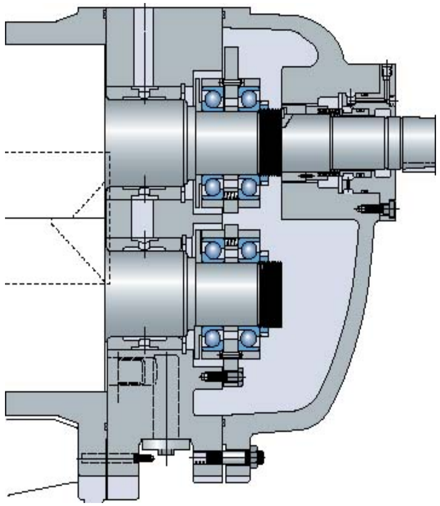
Twin Screw Compressors – Bearing Arrangements

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.

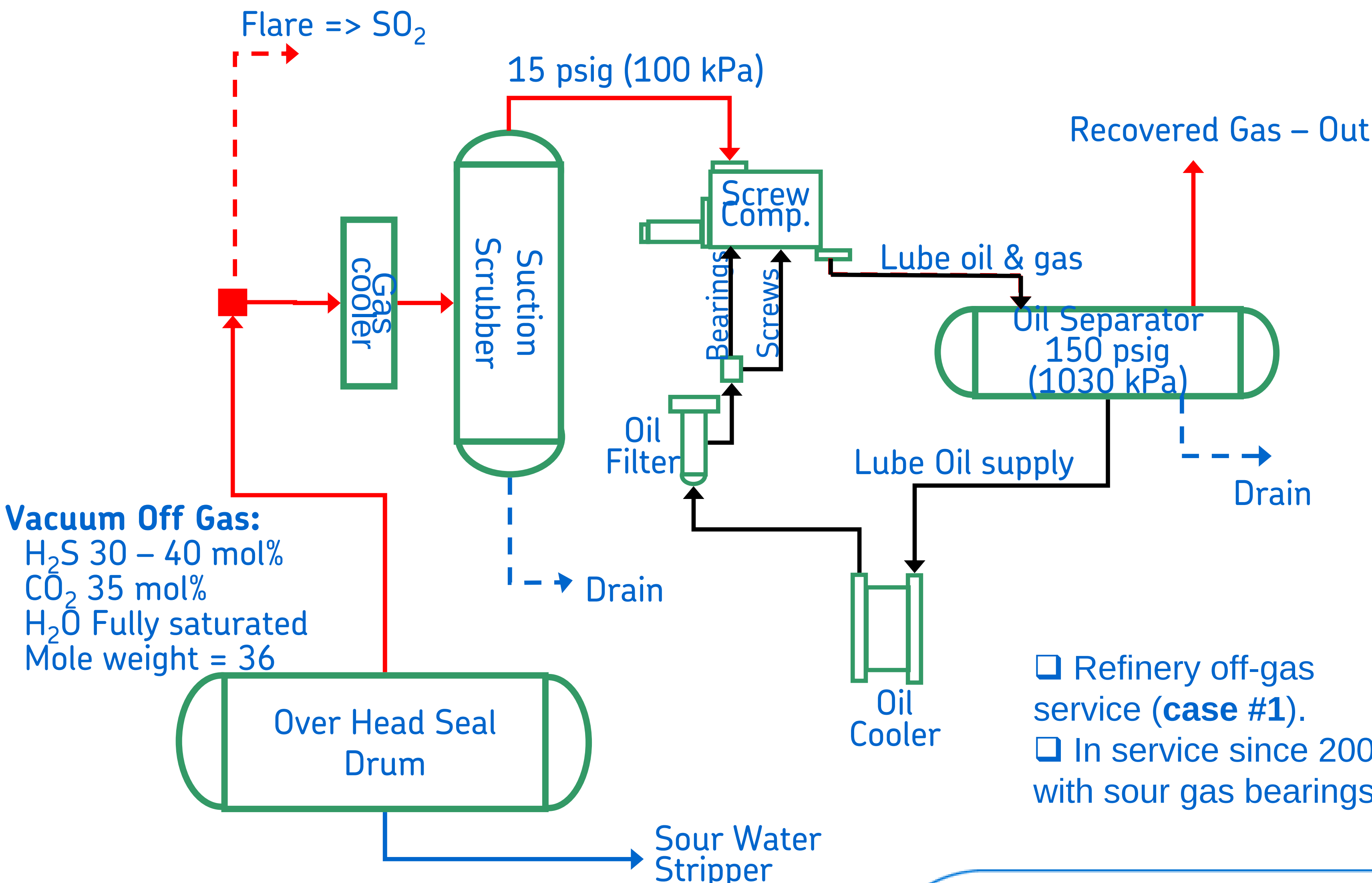
⇒ The oil pickup contamination from the process gas

Bearings & Materials

Rolling bearings	Steel rings	Rolling elements	Cage
Conventional	Common bearing steel *	Common bearing steel *	Steel or brass
Sour gas	Super-tough stainless bearing steel **	Bearing grade silicon nitride ceramics ***	Glass fiber reinforced PEEK or Single piece brass

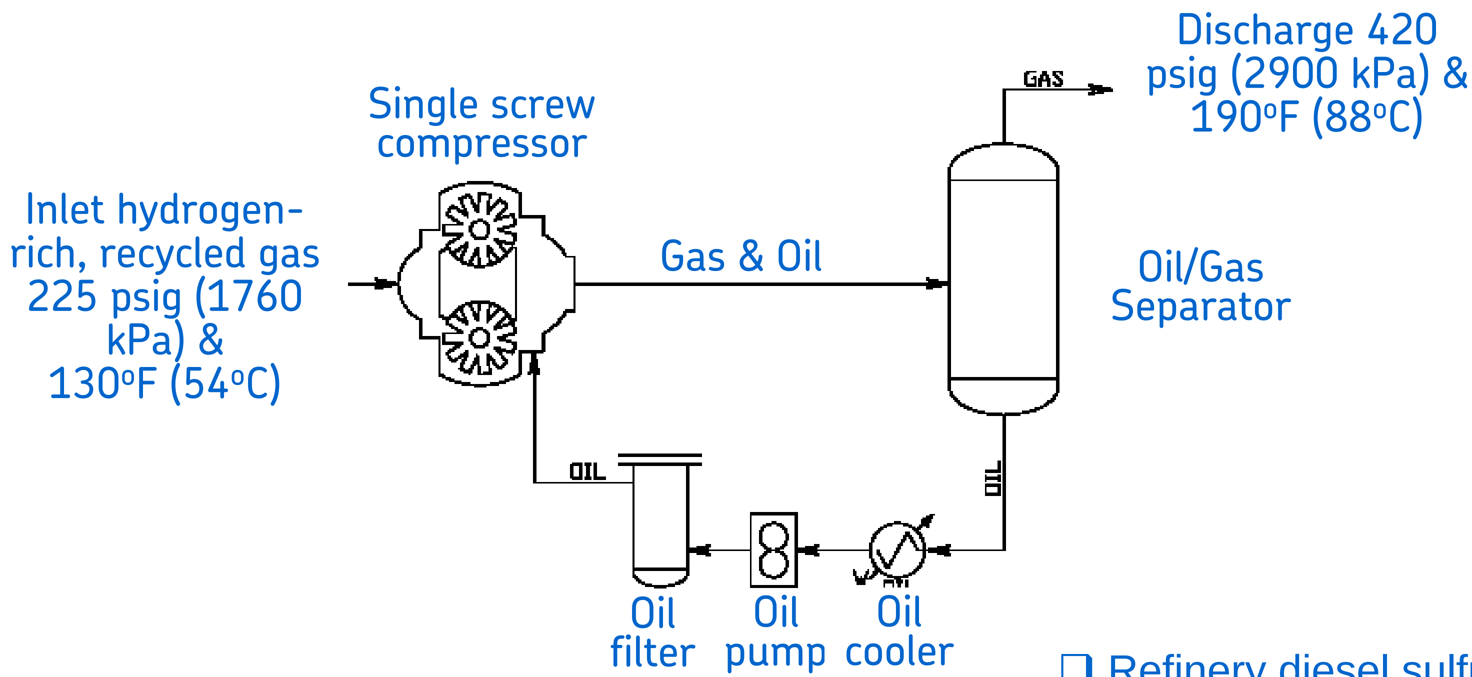
* AISI 52100 type; ** AMS 5898 & SKF hardening specification; ***ASTM F2094M - 11 Standard Specification for Silicon Nitride Bearing Balls plus SKF specifications

Process Flow: Oil-flooded Twin Screw Compressor



- ❑ Refinery off-gas service (**case #1**).
- ❑ In service since 2004 with sour gas bearings.

Process Flow: Oil-flooded Single Screw Compressor



Hydrogen recycle single screw compressor with SKF sour gas bearing. In a diesel sulfur reduction process.

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

Gas Conditions vs. Cases

Case	#	1	2	3	4
	Unit	VRU/Off-gas	Gas well boosting	Hydrogen-rich service	Recip boosting
MW_{avg}	g mol	36	20	9	41
$k_{suction}$	*k (*k)	0.031 (18)	0.052 (30)	0.23 (132)	–
CO_2	mol%	35%	5.5%	0.4%	70%
H_2S	mol%	40%	5.5%	0.01%	30%
H_2	mol%	n/a	n/a	65%	–
$P_{suction}$ (abs)	psi (kPa)	15 (100)	42 (288)	270 (1860)	–
$p_{H2S, suct}$ (abs)	psi (kPa)	6 (40)	2.3 (16)	0.03 (0.2)	–
In situ pH_{suct}	–	4,0	4.1	4.5	–

VRU = Vapor Recovery Unit; **MW_{avg}** = Molecular weight of compressed gas; **()** = Estimation, Clarification or ISO units; **$P_{suction}$** = pressures of gas at suction; **$p_{H2S, suct}$** = partial pressure of H_2S at suction and discharge; ***In situ* pH** = estimation by using the combined partial pressure of H_2S and CO_2 according to ISO 15156-2:2009

Thermal conductivity: ***k** = Btu ft/(hr ft2 ^oF); (k*) = mW/mK

Mechanical and Process Condition vs. Cases

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

* H_2S + CO_2 >40 mol%, dew point difficult to define; $DewP_{discharge}$ = 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 grove 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

Case	#	1	2	3
	Unit	VRU/Off-gas[2]	Gas well boosting	Hydrogen-rich service
Type	–	Twin	Twin	Single
Conventional	Years	< 0.5	1	0.2
Sour gas	Years	~ 3	> 5	>3 (?)
$p_{H2S,\ suction}$ **(abs)**	psi (kPa)	6 (40)	2.3 (16)	0.03 (0.2)
In situ pH_{suct}	–	4.0	4.1	4.5

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.

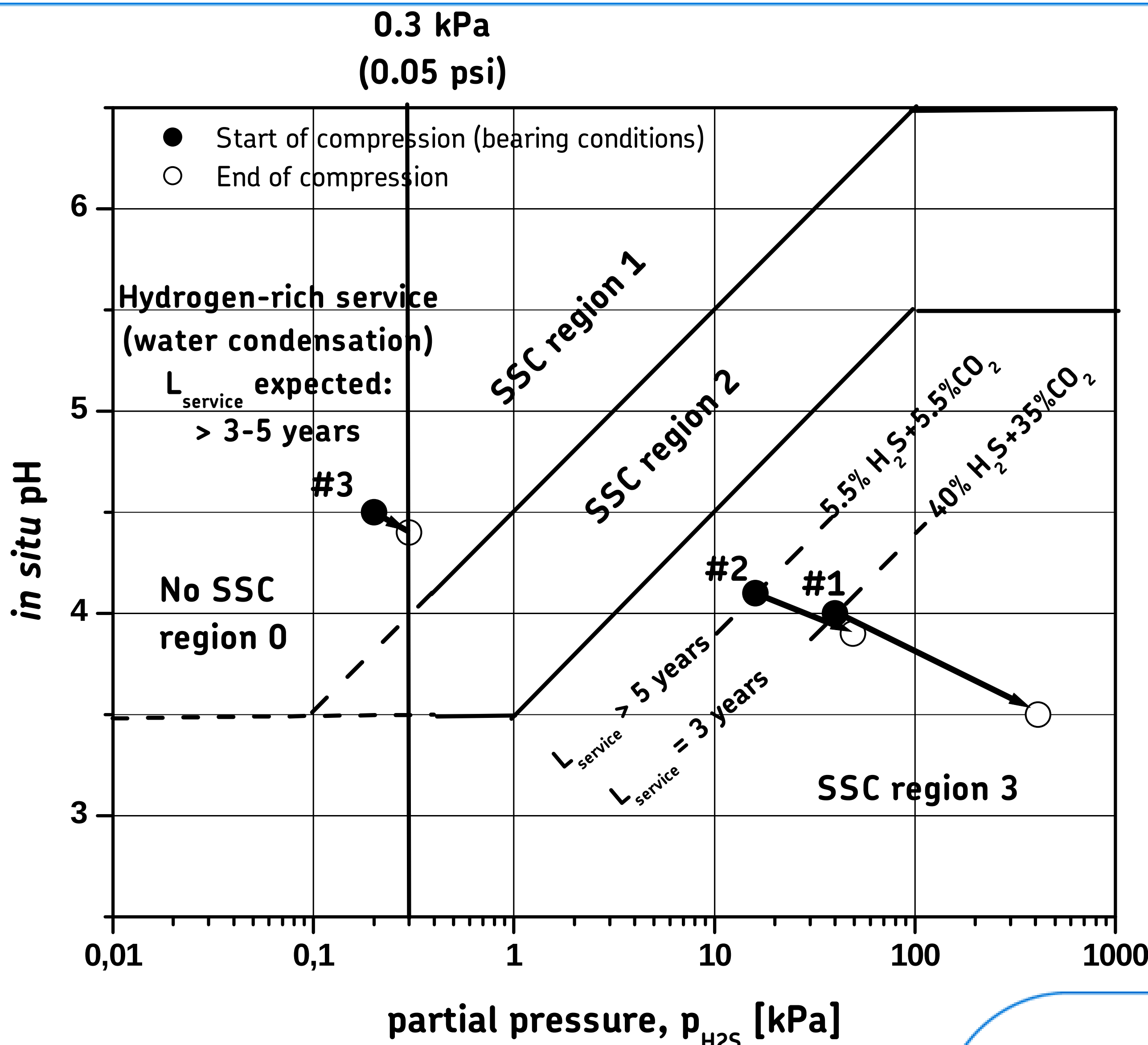
The diagram plot:

X-axis – log pH2S — Partial H_2S pressure

Y-axis – *In situ* pH — i.e. pH at service given by the combined partial pressures of H_2S and CO_2.

- ❑ p_i (partial pressure of gas i) = y_i (mol fraction of gas i) x $P_{suction}$ (total pressure at suction)
- ❑ kPa = psi x 6.895
- ❑ *In situ* $pH_{20C} = 4.9 – 0.5 \log(p_{H2S} + p_{CO2})$

Service-life Diagram for Sour Gas Bearings under SSC



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

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