METS III

MIDDLE EAST TURBOMACHINERY SYMPOSIUM

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Premature Dry Gas Seal Failure on a Sales Gas Centrifugal Compressor

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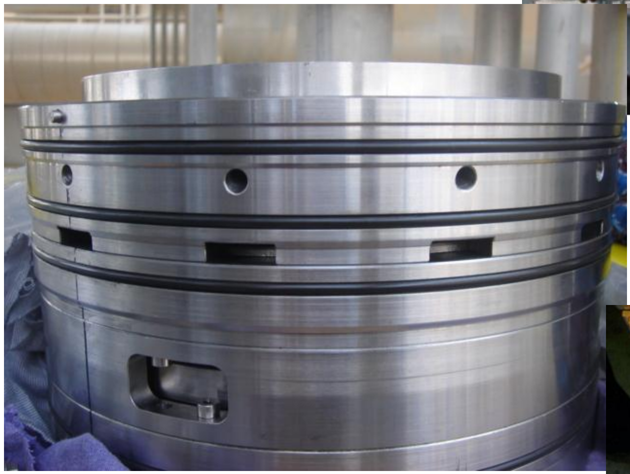


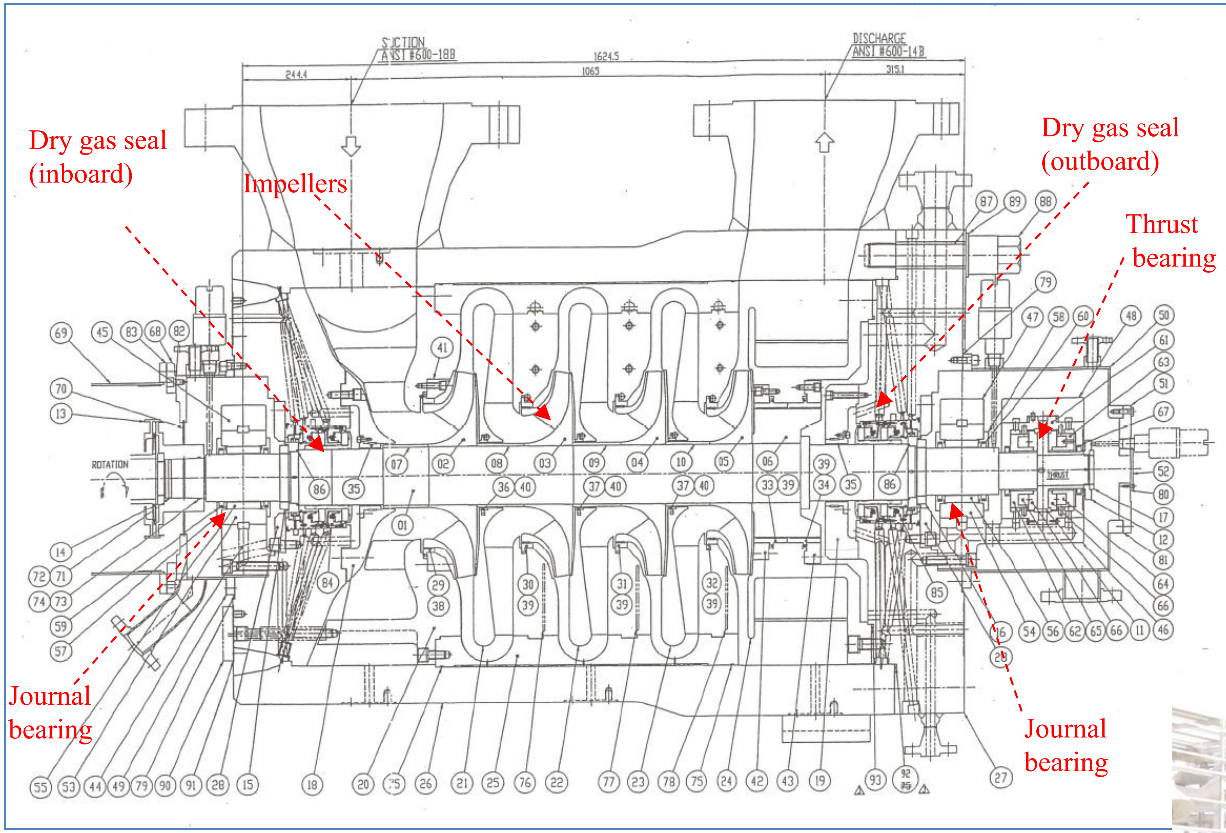
Introduction

- On Saturday, July 7, 2012, **sales gas compressor K002D tripped due to high outboard dry gas seal first leak pressure** (tag 64PI-854).

- The compressor was kept stopped for an investigation, which confirmed that an **actual dry gas seal (DGS) failure had happened on the machine;** dry gas seal rupture disk open, dry gas seal leak lines full with lube oil, compressor uncoupled and found not be able to rotate, etc.

- The installed **dry gas seal set were just installed 10 months ago** in September 2011, following a complete K002D compressor overhaul due to a DGS failure.

Introduction



Machine: Barrel type centrifugal compressor, 4 impellers.

Fluid: Sales gas (approx. mol.%: 75% methane, 10% ethane, 5% propane).

Speed: 9579 rpm.

Rated suction pressure: 458 psia.

Rated discharge pressure: 965 psia.

Rated flow: 351.9 MMscfd

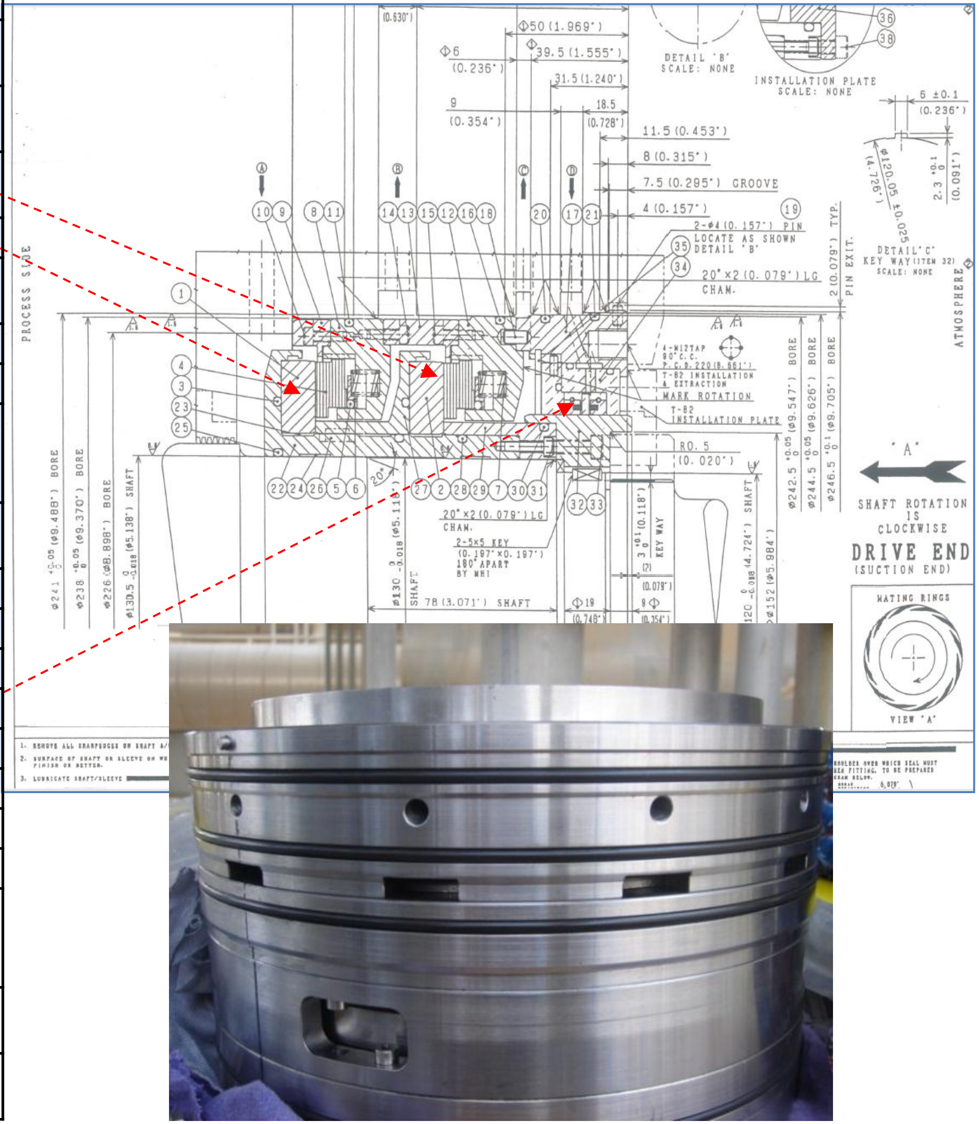
Total power: 15268 HP / 11.375 MW

Year constructed: 1998

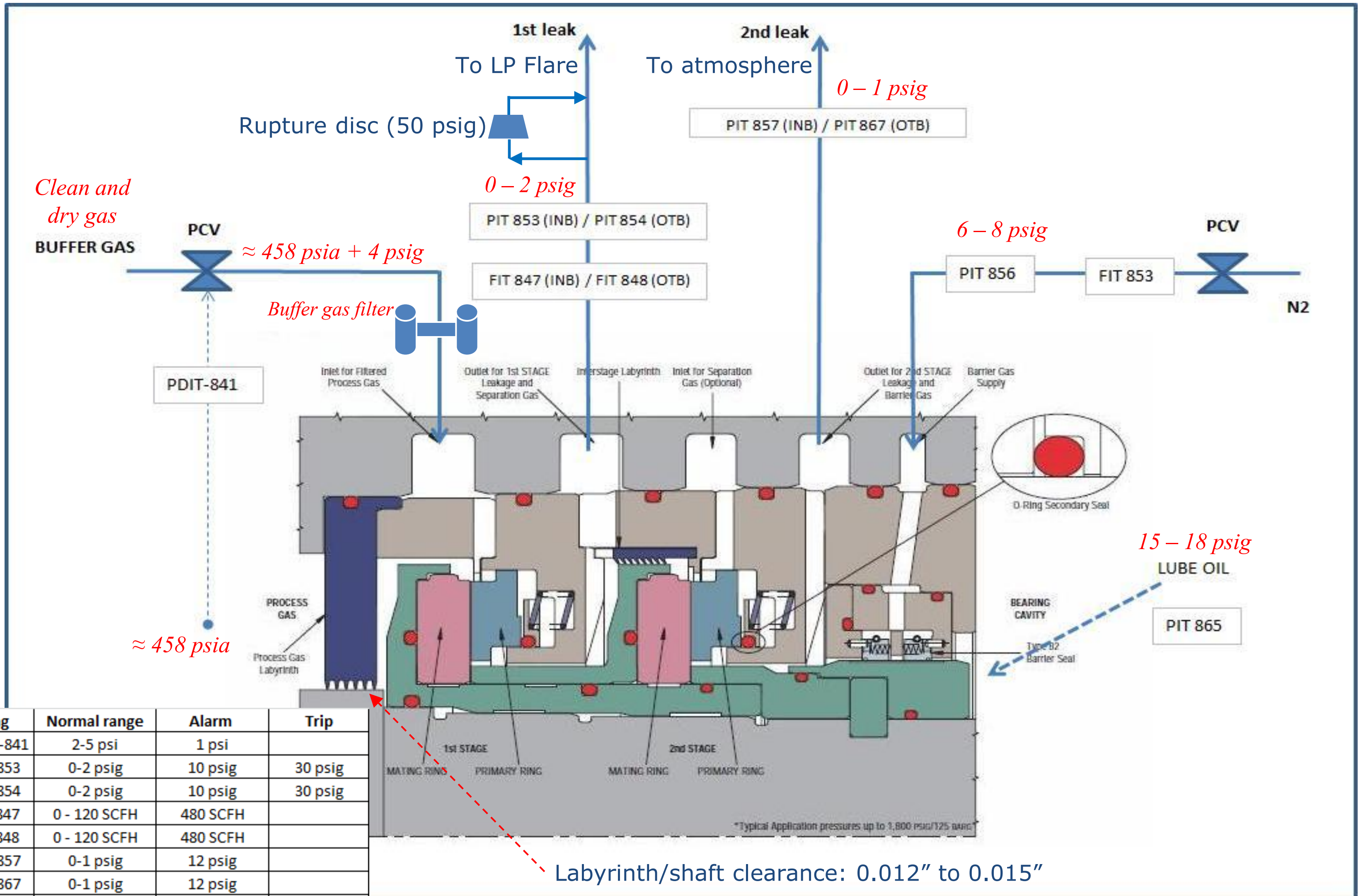
Year commissioned: 2001/2002

Introduction

Seal Application	
Seal Type	Unidireccional rings (one direction of rotation), Tandem Arrangemnet
1st seal rotating ring/ stationary ring	Tungsten Carbide/Carbon
2st seal rotating ring/ stationary ring	Tungsten Carbide/Carbon
Seal Size/Shaft Size	6.625 inches / 130 mm
Allowable Axial Movement	+/- 2.54 mm Including Installation Variance
Allowable Radial Movement	+/- 0.6 mm Except Labyrinth
Operating Conditions and Leakage Rates	
Process Gas/M. W.	CH4 (73-74%) + other H.C. + H2S (<4 ppm) + H20 (0.1-0.11%)/M.W. = 17.82-21.97
Shaft Speed	9,300 rpm (RATED)/9,765 rpm (FUTURE)
Temperature	88.3 ° C (RATED)/95 ° C (FUTURE)
Pressure	32.54-41.04 barG (486-612 psia)
Seal Buffer Gas	Filtered Process Gas
Tertiary Seal	
Seal Arrangement	Barrier Seal With Hard Coated Sleeve
Seal Size	165 mm
Barrier Gas Source	100% Nitrogen
Method of Supply	Controlled Pressure/Flow Monitoring
Controlled Gas Pressure	Min. 0.15 barG (2.15 psig)/Nor. 0.45 barG (6.52 psig)/Max. 1.0 barG (14.50 psig)
Gas Flow Rate per Seal End	38 std. ltr./min (1.34 SCFM) at 0.45 barg (6.52 psig)
Minimum Operating Pressure	0.15 barG (2.15 psig) Press switch low to be activated



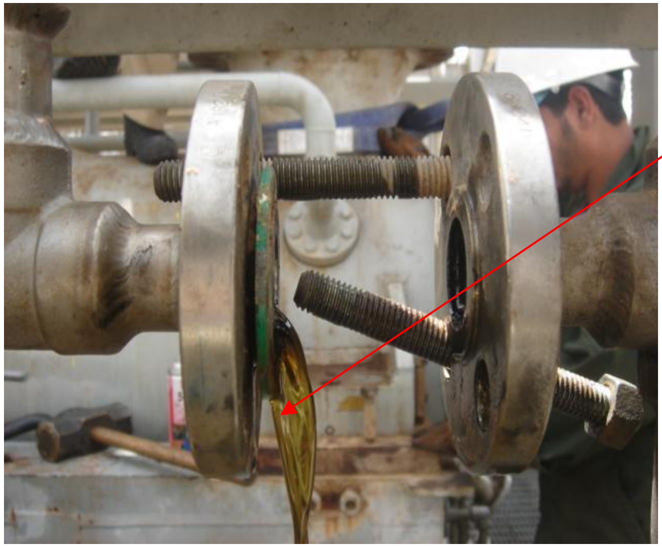
Introduction



Fluid	Tag	Normal range	Alarm	Trip
Buffer gas	PDIT-841	2-5 psi	1 psi	
Buffer gas	PIT853	0-2 psig	10 psig	30 psig
Buffer gas	PIT854	0-2 psig	10 psig	30 psig
Buffer gas	FIT847	0 - 120 SCFH	480 SCFH	
Buffer gas	FIT848	0 - 120 SCFH	480 SCFH	
N2	PIT857	0-1 psig	12 psig	
N2	PIT867	0-1 psig	12 psig	
N2	PIT856	6-8 psig	3 psig	
N2	FIT 853	50-100	204 SCFH	
Lube oil	PIT865	15-18 psig	11.6 psig	6.5 psig

Field Mechanical Findings

- **Lube oil spread all around the machine surroundings,** through the secondary seal leak line discharge to the atmosphere (3rd floor compressor bay).
- **Compressor shaft was found to be stuck/not rotating.**
- **Inboard dry gas seal 2nd leak drain** to sewage (1st floor): Some traces of lube oil.
- **Inboard dry gas seal 1st leak drain** to sewage (1st floor): Without any liquid.
- **Outboard dry gas seal 2nd leak drain** to sewage (1st floor): **Lube oil.**
- **Outboard dry gas seal 1st leak drain to** sewage (1st floor): **Lube oil and hydrocarbons liquid.**
- **Outboard dry gas seal 1st and 2nd leak lines** (1st floor): **Completely filled with lube oil.**



Outboard dry gas seal 1st and 2nd leak lines were completely filled with lube oil.

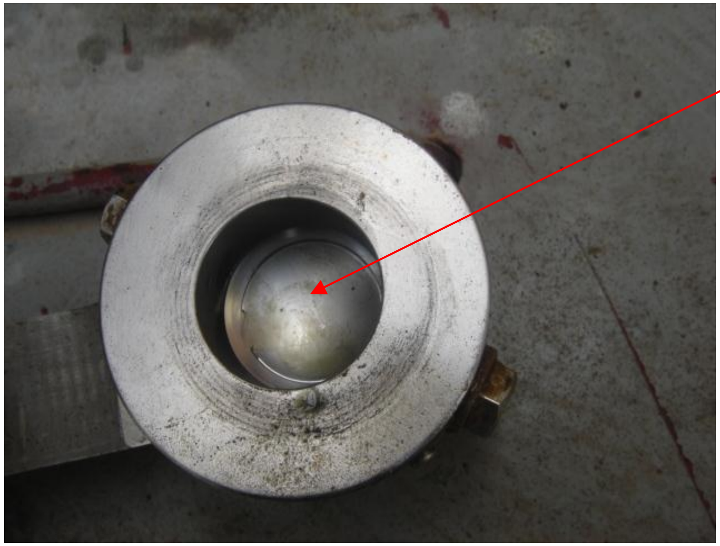
Field Mechanical Findings

- **Outboard dry gas seal 1st leak line rupture disk on 1st floor: rupture and full of debris (metal and other particles).** This debris appears to belong to dry gas seal internal components (rotating and static rings, springs, etc.).

- **Inboard dry gas seal 1st leak line rupture disk on 1st floor**: **Not damaged.** Lube oil only on the vent side of this rupture disc (no lube oil coming from the inboard dry gas seal 1st leak line).

- **Filter for N2** supply to the dry gas seal on 1st floor: **Not plugged and in good condition**. There were no moisture or liquid traces on this filter.

- **Dry gas seal buffer gas filters** on 1st floor (in service and standby): **Liquid inside both of them**.



Inboard dry gas seal 1st leak line rupture disk was intact.

Outboard dry gas seal 1st leak line rupture disk was found ruptured and full of debris.

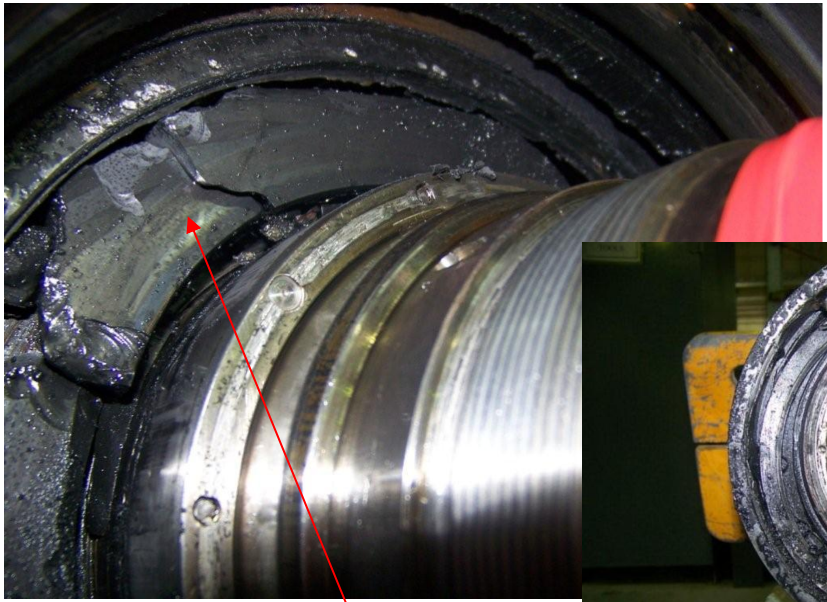
Shop Mechanical Findings

- **Inboard dry gas seal: Not seriously damaged** (just some medium scratches in seal journal area), a very little amount of lube oil was found on the tertiary seal area.
- **Outboard dry gas seal tertiary seal: Oil contaminated and with black deposit** but no visible wear or scratches.

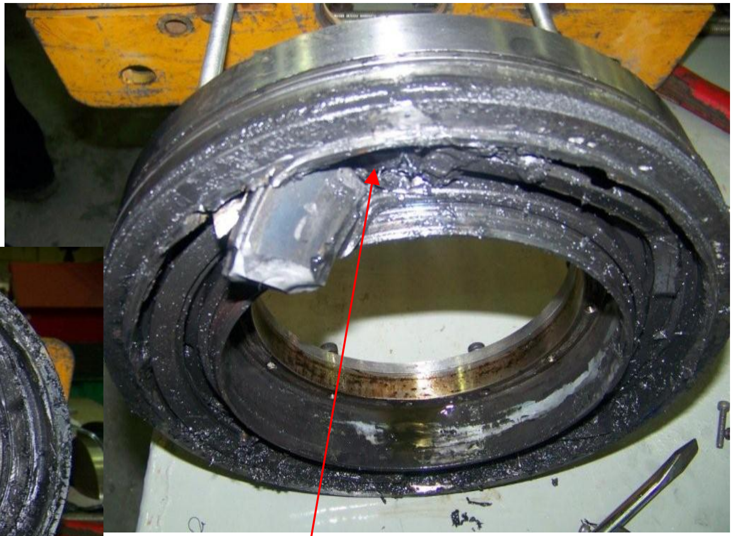
Outboard dry gas seal tertiary seal.

Shop Mechanical Findings

- **Outboard dry gas seal 2nd seal: Springs had disappeared**, the **rotating ring (tungsten carbide) and the stationary ring (carbon) were found broken** in pieces.
- **Rotating ring (tungsten carbide) and stationary ring (carbon) of the outboard dry gas seal 1st seal were not broken**. The seal faces have scratches, on the stationary ring (carbon) a little piece was missing. The spring was in good conditions and in place.
- The process side labyrinth/shaft clearance on both inboard and outboard dry gas seal has found be **around 0.017" (design values: 0.012" to 0.15"), value acceptable**.

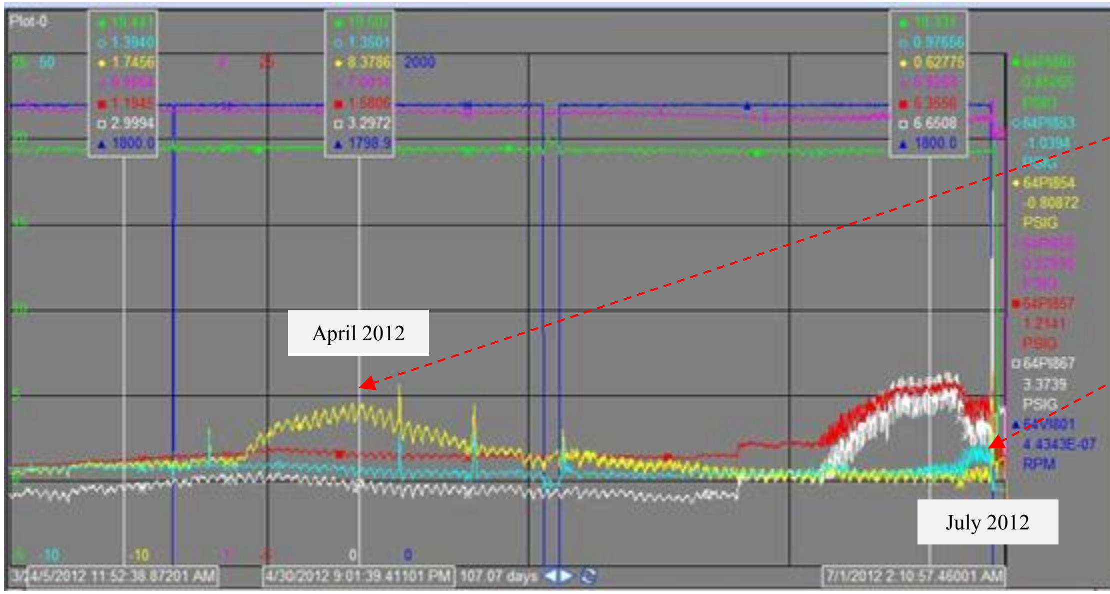


Outboard DGS 2nd seal, brooken rotating ring.

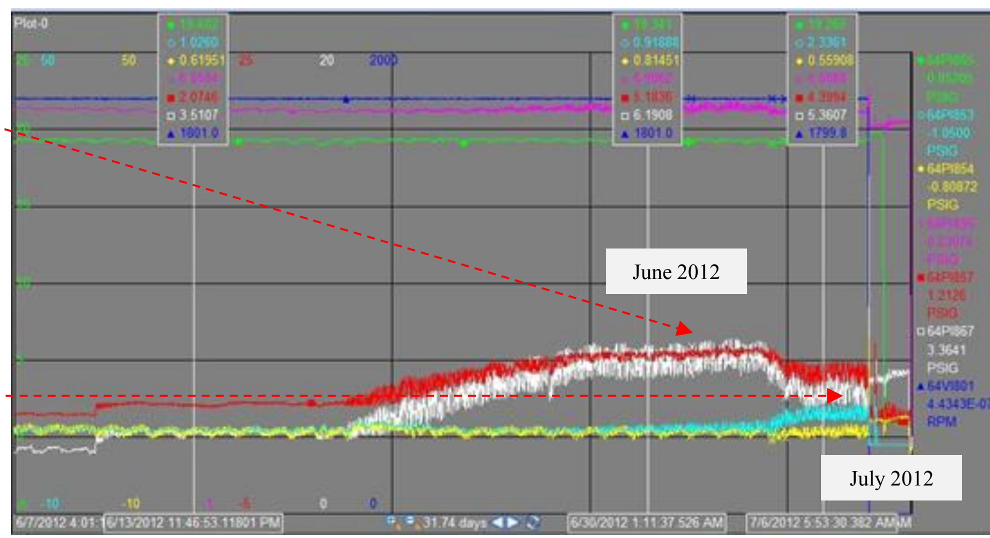


Outboard DGS 2nd seal, brooken tungsten carbide pieces.

DCS Findings

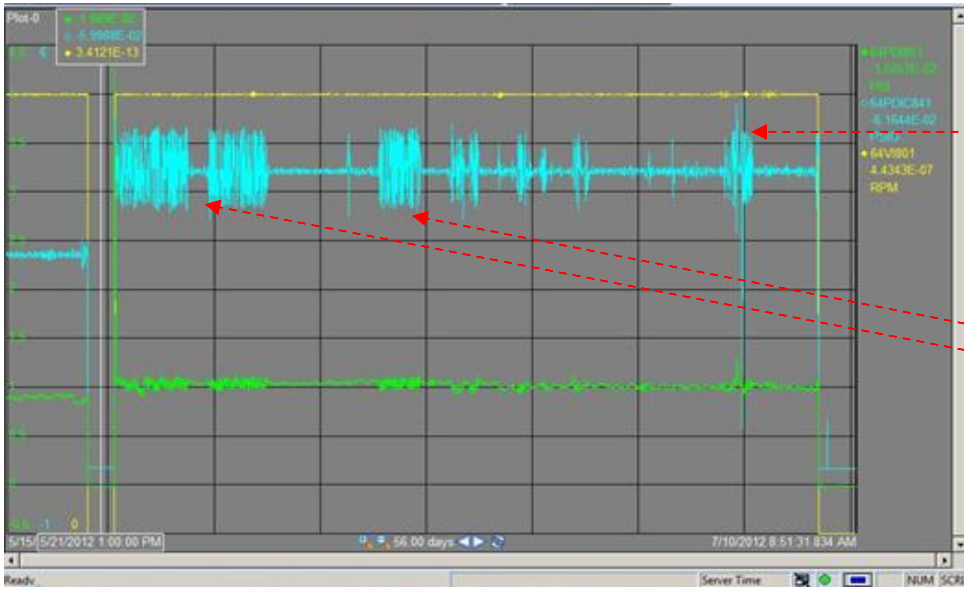


- DGS 1st leak pressure outboard side (tag PI854) **reached 8.3 psig on 30-04-2012** and for around 2 weeks had higher values than the normal values of 0-2 psig.
- DGS 1st leak pressure inboard board side (tag PI853) on **04-07-2012 start increasing to 4 psig until the trip on 07-07-2012,** normal values 0-2 psig.



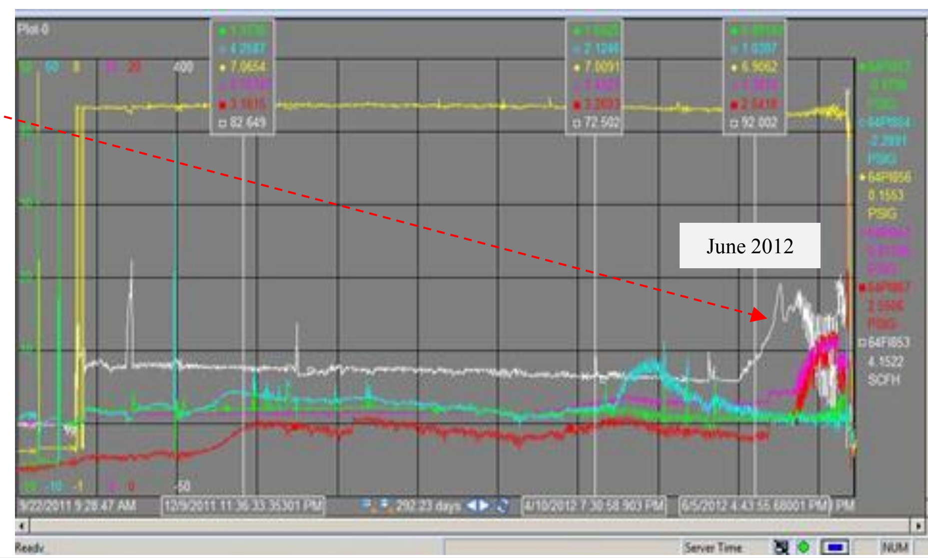
- 2nd leak pressure inboard and outboard side (tags PI857/PI867) **started to rise around 20-06-2012 and reach 7/6 psig on 30-06-2012 then dropped to 5/4 psig until the trip on 07-07-2012**, normal values 0-1 psig.
- 6 days before the failure, around 01-07-2012 several DGS parameters start **showing more fluctuations than normal.**

DCS Findings

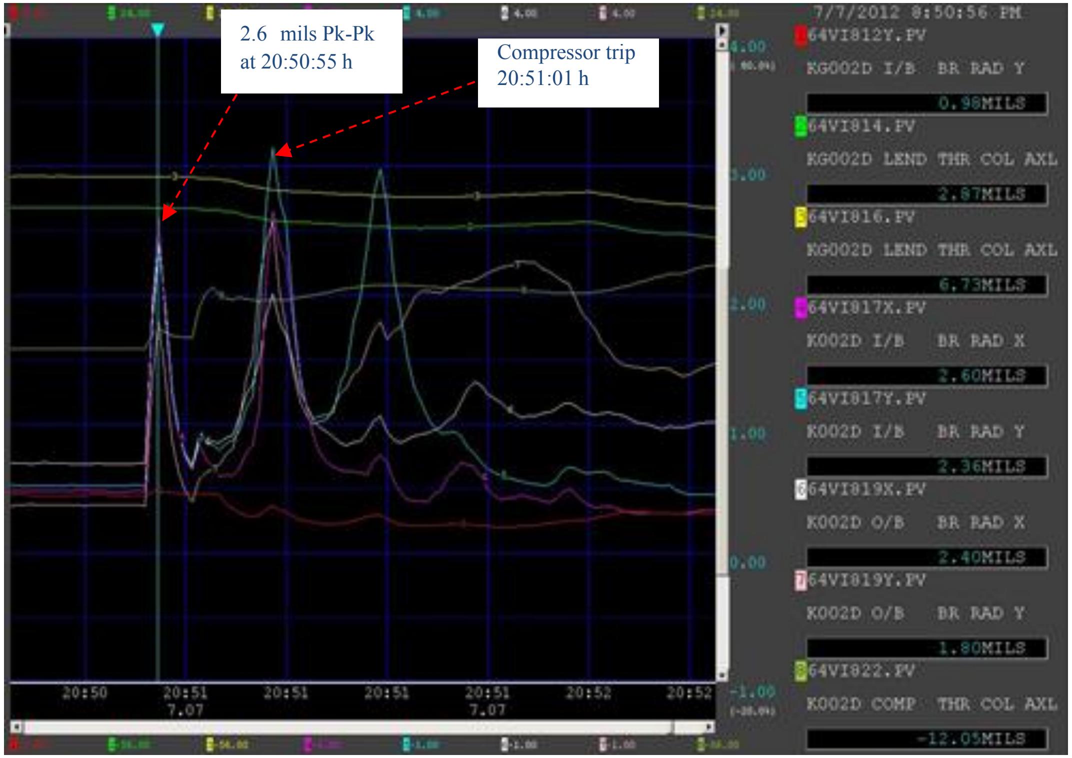


- The **DGS buffer gas ΔP (tag PDIT841) values start fluctuating** around 2:30 h before the trip on 07-07-2012.
- Between 02-07-2012 to 03-07-2012 (5-6 days before the failure), the **DGS buffer gas ΔP showed several times unusual fluctuations**.

- The tertiary seal N2 gas supply flow (Tag FI853) **increase to 168 SCFH on 14-06-2012 and drop again** to normal values of 80-90 SFCH. It increase back to around 150-160 SCFH on 04-07-2012 and maintain this values until the trip on 07-07-2012.
- The lube oil pressure (PIT 865) to the bearings has been around **20-21 psig, which is higher than the COMPRESSOR OEM recommended values of 15-17 psig**.



Vibration Monitoring System (VMS) Findings



- The vibration monitoring system (VMS) is **configured with 3 seconds filter time delay** for the danger alarm (i.e., HH vibration) to avoid trips on vibration spikes.

- As per API 670 Machinery Protection System section 5.4.1.5:

  *"With exception of electronic over speed detection, fixed time delays for shutdown (danger) relay activation that are field changeable (via controlled access) to require from 1 to 3 seconds sustained violation. **A delay of 1 second shall be standard**."*

- Before the trip of 07-07-2012 20:51:01 h due to the DGS 1st seal leak outboard, there was a **vibration peak 2.36-2.6 mils Pk-Pk** at 20:50:55 h (compressors bearings) above the shutdown value (2.26 mils Pk-Pk) that lasted no more than 1 second.

- As **vibration peak at 07-07-2012 20:50:55 h of 2.36-2.6 mils Pk-Pk** lasted less than the current 3 second time delay it didn't cause a trip.

Analysis

- Considering the major findings we have described before, the theoretically possible causal factors for this failure are (as per API dry gas seal subcommittee RCA table):

  - Dry gas seal secondary seal failure.
  - Dry gas seal N2 tertiary seal failure.
  - Excessive lube oil supply to compressor bearing.
  - Liquid in dry gas seal buffer gas.
  - Reverse pressurization-pressure deformation of the dry gas seal 2nd seal.
  - Excessive vibration.
  - N2 failure or contamination.

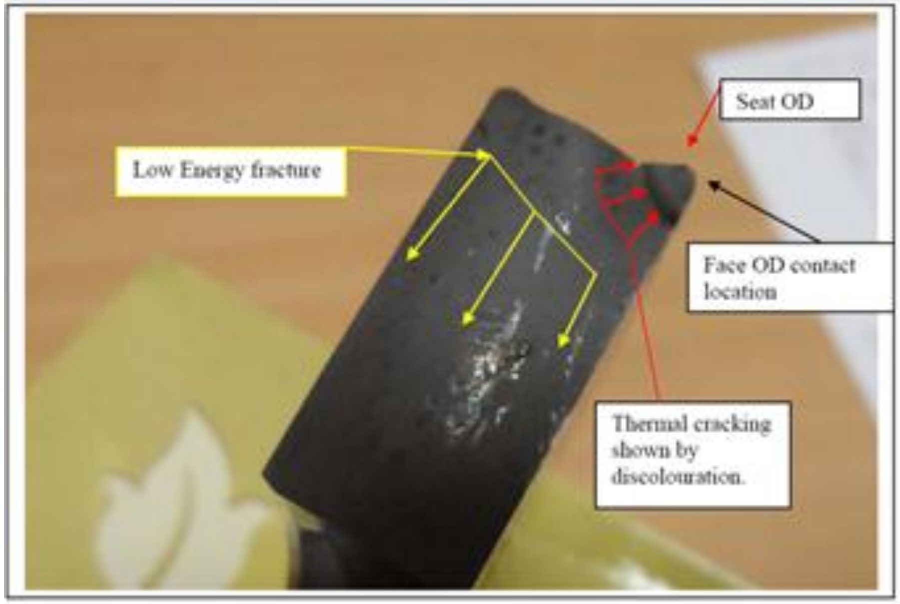
- During our investigation we ruled out two of the previous theoretically possible causal factors:

  - **Excessive vibration** – The trends show that the compressor vibrations were stable within the acceptable values (below alarm) without any spikes or increasing trend.

  - **N2 failure or contamination** – The trends values show that the N2 pressure has always supply whenever the lube oil system was working. The N2 supply filter has without any moisture/liquid, there were some particles but were retained by the filter mesh.

- **We asked DGS manufacturer to perform a failure analysis on both dry gas seal (inboard and outboard).**

Analysis

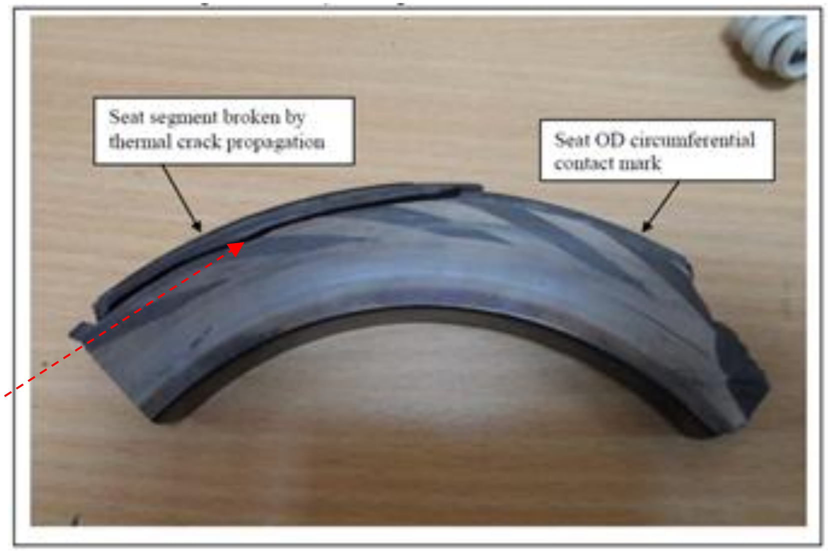


- The DGS manufacturer investigation report states the cause for this seal failure was due to **reverse pressurization of the dry gas seal 2nd seal, outboard side**.

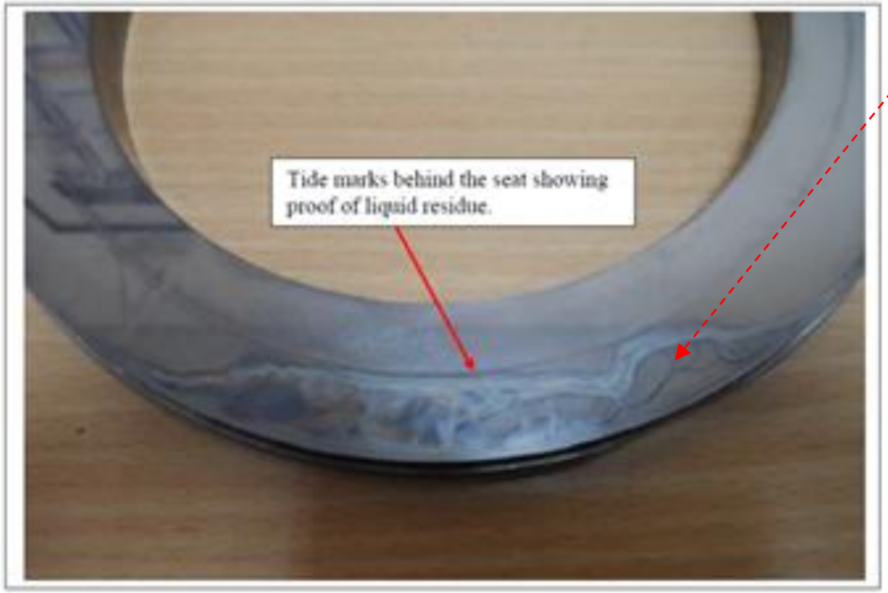
- Reverse pressurization occurs when the **pressure on the ID of the seal is higher than the OD of the seal** (normally the seal operated with the pressure on the OD higher than on the ID of the seal).

- **Reverse pressurization tends to close the faces at the outside diameter producing a divergent gap,** which can cause thermal stress at the OD of the tungsten carbide seat due to localized high temperature.

- The localized **thermal stress create and propagated axial cracks** through the seat which can cause a catastrophic DGS failure.



Analysis

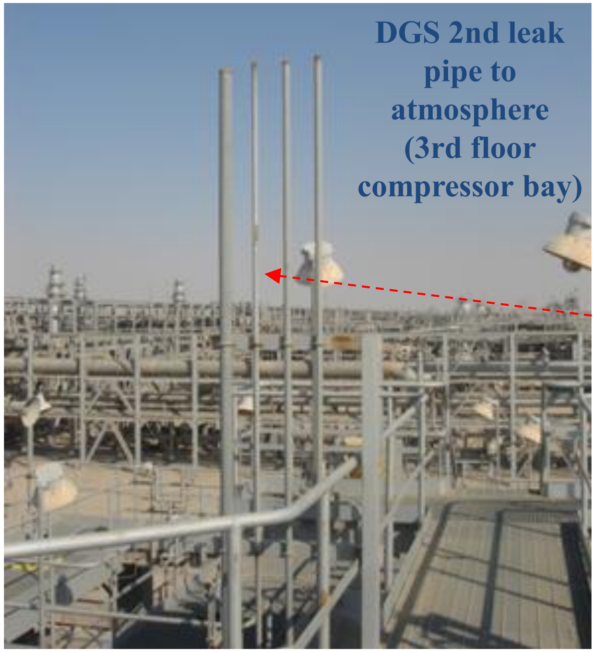


- There were traces of liquid residues on the dry gas seal 2nd leak seat, outboard side;
- API 617 "Axial and Centrifugal Compressor and Expanders for Petroleum, Chemical and Gas" identifies the possibility of **reverse pressurization causing DGS failure**:

  "2.8.4.2 Self-acting dry gas seals shall be provided with connections to allow the user to inject filtered gas, and to protect against reversal of differential pressure during sub-atmospheric operation. Note: Some self-acting dry gas seals can be destroyed by reversal of pressure differential."

- As stated in article *"Design Improvements Enhance Dry Gas Seal's Ability to Handle Reverse Pressurization" of the Turbomachinery Symposium*, **dry gas seal failure can occur for values of around 6 psig reverse pressurization in running conditions.**
- The **maximum reverse pressurization we had on the dry gas seal 2nd seal was of 4-6 psig during around 10-15 days before the failure (running conditions).**
- **Reverse pressurization under static conditions can also cause damage** to the DGS (*"Dry Gas Seal Retrofit" article of the Turbomachinery Symposium*) and should be limited normally around 10 psig.

Analysis



- The possible causes for reverse pressurization of the dry gas seal 2nd seal in running conditions are:
    - N2 supply failure or contamination (*already ruled out before*).
    - N2 barrier seal failure.
    - 2nd leak vent line blockage.

- DGS manufacturer **didn't find any major or severe damage to the N2 barrier seal failure**.

- On the K002D failure of September 2011, **all the dry gas seal console and pipe was found completely full with lube oil for both DGS ends.**

- There is the possibility that **some oil from the September 2011 failure to have been trapped** on the 2nd vent line low points (between the 1st and 3rd floor of the compressor bay), which may have **contributed to the 2nd vent dry gas seal leak line blockage** of July 2012.

Analysis

- Dry gas seal technology has developed around 1970s and **its first oil and gas industrial application were around 1980s**.
- DGS has been applied in the process gas centrifugal compressor **for around 35-40** years but there is still **no complete and extensive industry accepted standard for dry gas seal and their support system design**.
- The API has only started addressing gas seal design in its standard **"API Std 614 - Lubrication, Shaft-sealing and Oil-control Systems and Auxiliaries" in 1999.**
- The **sales gas compressor K002 A-D were design around 1998-1999** so at the time API didn't even address the dry gas seal technology design and reliability concerns.
- Only in **"API Std 614 - Lubrication, Shaft-sealing and Oil-control Systems and Auxiliaries" latest edition (2008)** the dry gas seal support design is described much more in detail, but the API subcommittee on mechanical is still working on a new dry gas seal standard.

Conclusions

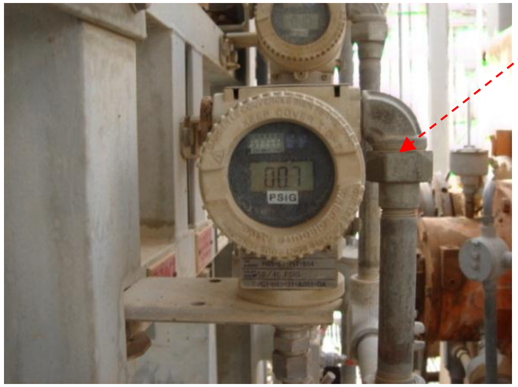
- Our final conclusion is that the K002D dry gas seal failure of July 2012 (outboard seal) was due to the **dry gas seal reverse pressurization of the 2nd seal, probably due to the 2nd leak vent line blockage/partial filling with oil.**

- This failure could have been prevented if the original **dry gas seal design and instrumentation by DGS manufacturer/ COMPRESSOR OEM made in 1999 had been properly setup** to protect our dry gas seal from reverse pressurization. In 1999, the DGS manufacturer already knew about such phenomena.

- The **liquid content that we found on the buffer gas was not the root cause** for this failure but will cause a dry gas seal failure in the long run.

Recomendations

- Change the **current DGS secondary leak pressure (PIT857/PIT 867) alarm from 12 psig to 4 psig** – DGS manufacturer recommendation accepted by compressor OEM.
- **Don't run the compressor lube oil system without having N2 supply to the DGS tertiary seal** – DCS interlock to prevent this situation.
- Change the **current time delay** setting for the vibration protection systems shutdown values **from 3 seconds to 1 second**, which is the standard value recommended by API 670.
- DGS instrumentation (pressure and flow transmitters) should be **replaced/sent to calibration every 5 years**.

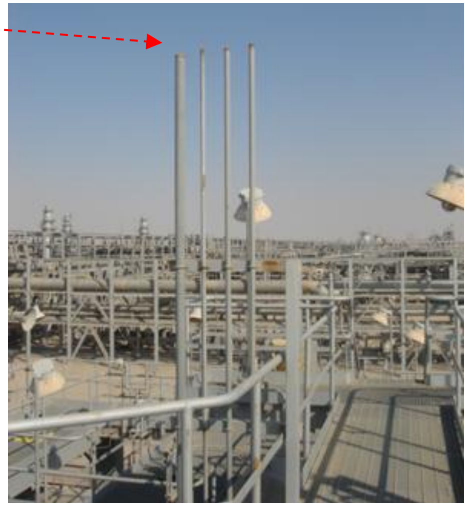


Recomendations

- **Normal lube oil pressure range should be around 15-17 psig** (set-point: 17 psig), the lube oil pressure must not higher than 17 psig, use PCV 874 to control this pressure.

- In all compressors dry gas seal replacement, **properly clean (by solvent, water, high air pressure, etc.) the 1st and 2nd vent leak line to the flare and the atmosphere between the compressor 1st floor and 2nd/3rd floor.**

- **Install a invert U-shape pipe at the end of the 2nd leak vent line** of all sales gas compressors to prevent dirt and liquid from entering the 2nd leak vent line.



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Thank you very much for your time!

Any questions, doubts, comments?