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Case Study on investigation and safe resolution of using instrument air as separation medium for Dry Gas Seals

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Abstract

During the independent Asset Integrity Review (i-AIR) audit conducted on one of the offshore production facilities, use of instrument air as separation medium for separation seal of the process gas booster compressors Dry Gas Seal units was noticed as a "Safety Issue". i-AIR report recommended to conduct an operational risk assessment to ascertain the risk of using instrument air and put forth any modifications and/or safeguards/controls needed to mitigate the risk to ALARP (as low as reasonably practicable) levels.

Accordingly, a risk assessment was conducted followed by a detailed engineering study which came out with various mitigation solutions.

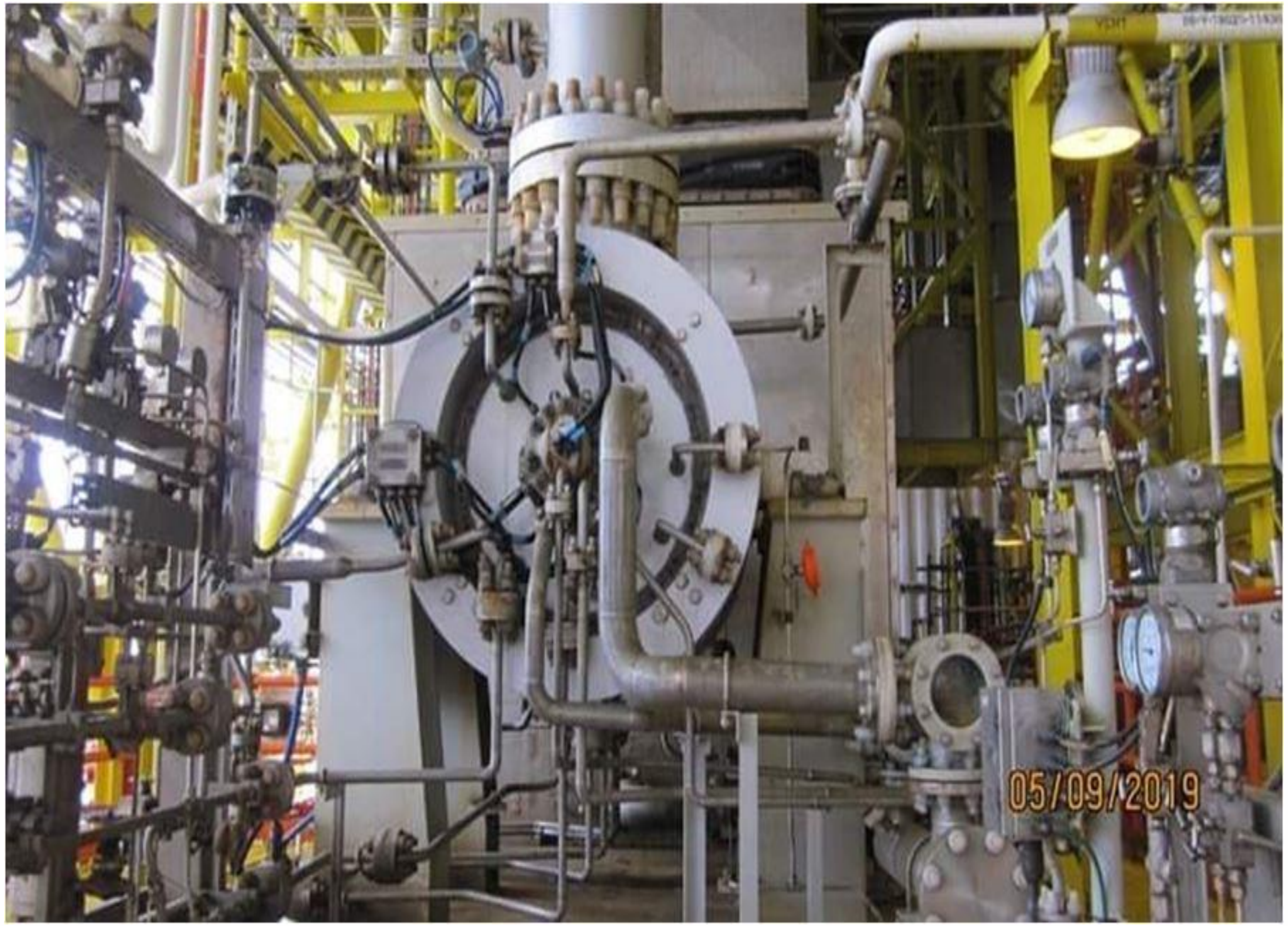
This case study will present the safety issues encountered, risk assessment conducted, mitigation solutions analyzed/evaluated, solutions implemented, results and lessons learnt.

Contents

Machine Details

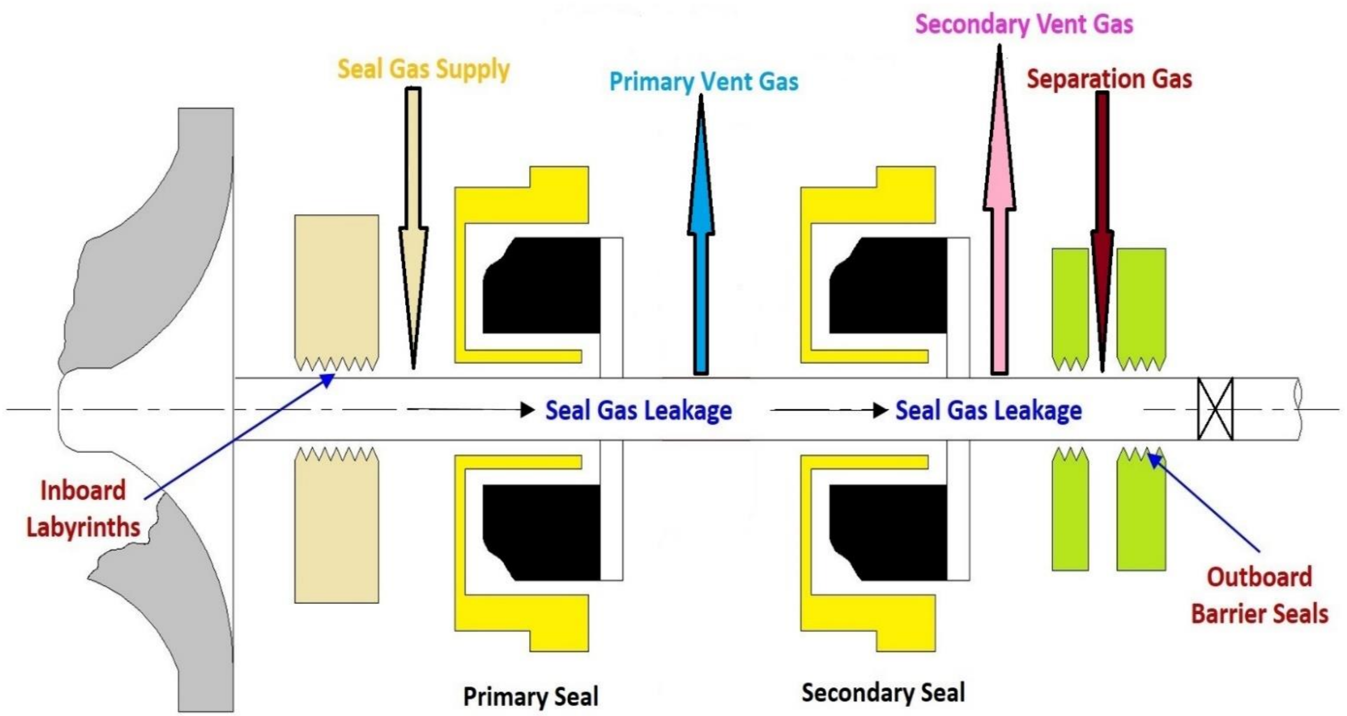
03 units of Gas Turbine Driven Booster Gas Compressors (multi-stage) at an offshore facility

Operating Data	
Suction Pressure	33.43 bara
Suction Temperature	44 deg C
Discharge Pressure	79.47 bara
Discharge Temperature	121.2 deg C
Inlet Volume	9017 m3/hr
Mol. Wt.	22.24 kg/kmol
Speed	8740 rpm
Train Power	10182 KW
Gas Composition (Mol. Frac.)	C_1=0.74, C_2=0.08
	C_3 = 0.03, C_n=0.02
	N_2 = 0.03, CO_2= 0.10

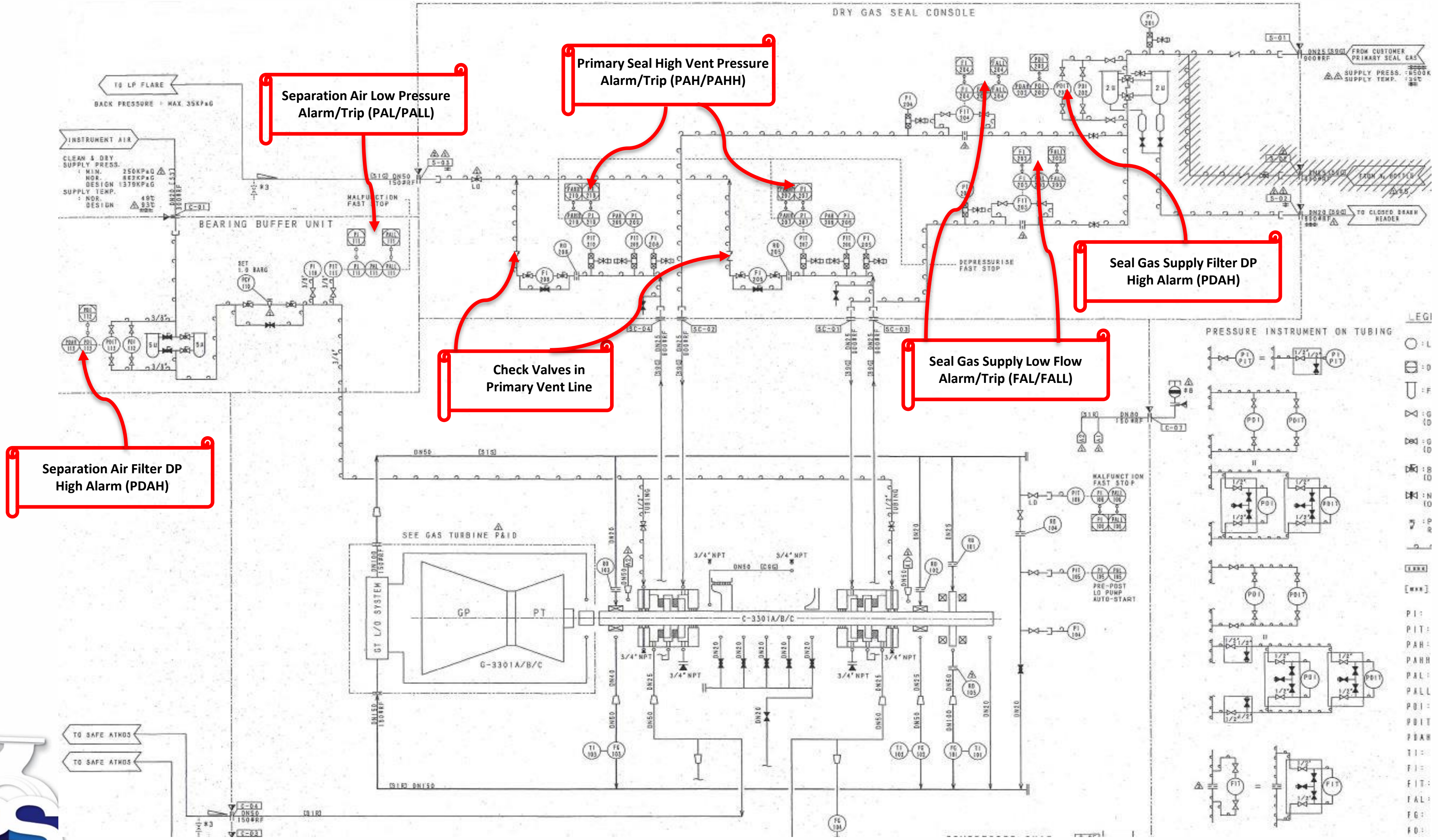


Dry Gas Seal System Schematic/Details

- Tandem arrangement without intermediate labyrinth
- Seal Gas Supply @ 65 barg, 39 deg C, 6.2 kg/min flow
- Seal gas supply filtration with 2um duplex filter assembly (99.9% Efficiency with Beta Ratio >/= 1000)
- Flow Control for Seal Gas supply
- Separation gas - Instrument air
- Process/Separation Seal Type - Labyrinth



Dry Gas Seal System P&ID-Existing Monitoring/Safeguarding



Problem Statement

- During the independent asset integrity review (i-AIR) audit conducted on the facility, use of instrument air as separation medium for separation seal was notified as “Safety Issue” as it is potentially possible to create an explosive environment in the seal system secondary vent when air mixes with combustible process gas. No risk assessment was sighted for the use of instrument air as separation gas during the Project Stage.

- Combustion within the secondary vent can occur if the process gas- to- air mixture is within the explosive limits and a source of ignition exists in the secondary vent. The worst-case scenario is a major failure of the primary seal with an unknown condition of secondary seal. Under this condition, the secondary vent would be exposed to higher levels of sealing gas leakage.

Introduction and Background

- Booster Gas Compressor units fitted with Tandem Dry Gas seal (DGS) without intermediate labyrinth.

- Instrument air being used as separation gas for the separation seal to isolate the dry gas seal cavity from the oil-bearing cavity and prevent oil ingress into the seal.

- Only the Primary DGS supply & vents are instrumented and monitored while there is no instrumentation & monitoring available for Secondary DGS vent lines.

- It was recommended to conduct an operational risk assessment to ascertain the risk of using instrument air and put forth any modifications and/or safeguards/controls needed to mitigate the risk to ALARP levels.

Risk Assessment & Management

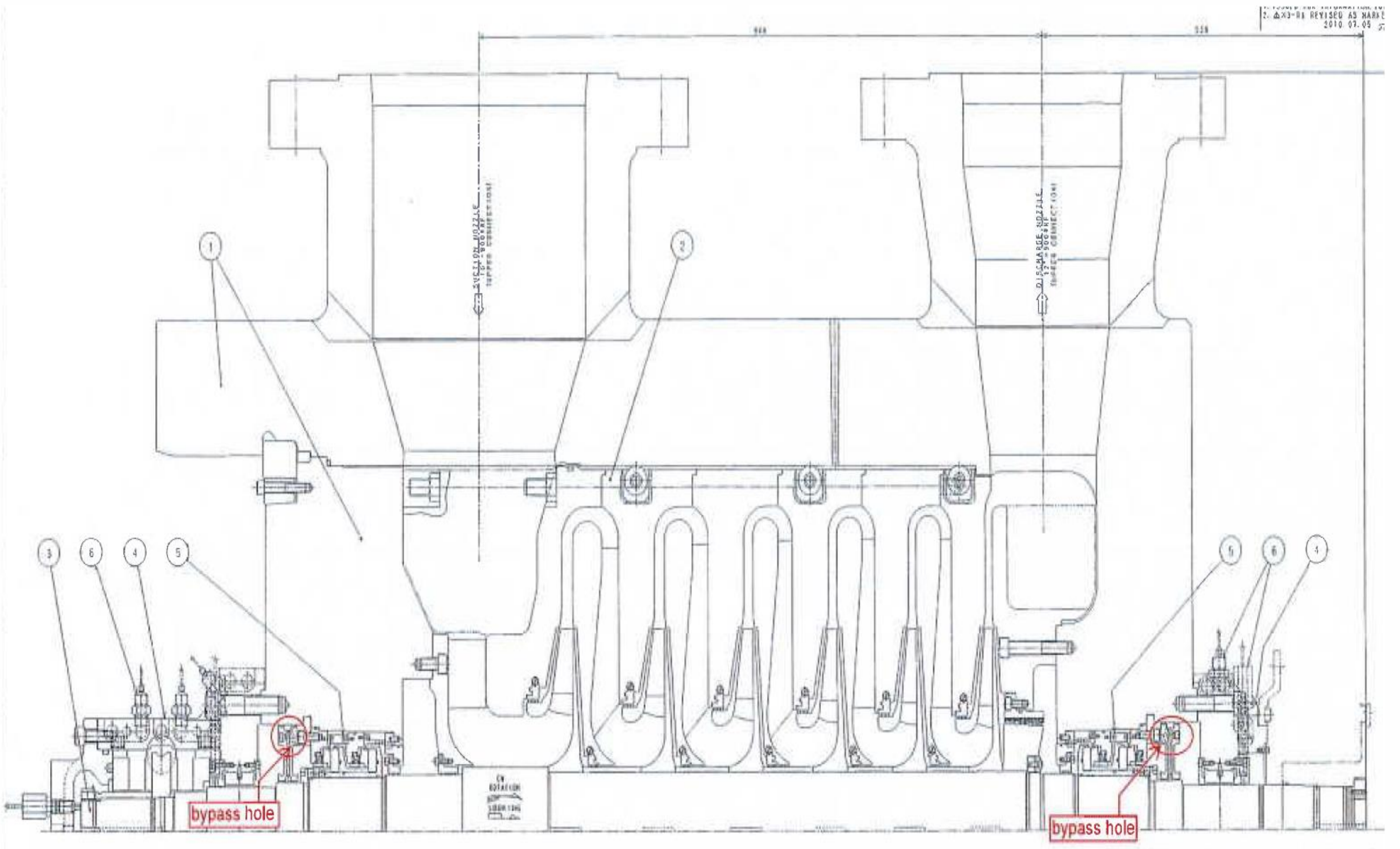
Possible Risk Scenarios:

RISK	POSSIBLE RISK SCENARIOS	Inherent Risk	Existing Safeguards/Controls & Monitoring	Final Risk
#1	**Seal Gas supply failure**	High	Yes (FAL/FALL on Seal Gas Supply) PI on DE/NDE Seal Gas Supply	Low
#2	**Failed Primary Seal**	High	Yes (PAH/PAHH on Primary Vent) FI on DE/NDE Primary Vent	Low
#3	**Failed Secondary seal**	High	No	**High**
#4	**Total/Partial loss of separation air => oil in DGS**	High	Yes (PAL/PALL on Separation Air Supply)	Low
#5	**Seal Gas Filter Differential Pressure High due to blocked/contaminated filters**	Medium	Yes (PDAH on Seal Gas Filter DP)	Low
#6	**Separation air Filter Differential Pressure High due to blocked/contaminated filters**	Medium	Yes (PDAH on Separation Air Filter DP)	Low
#7	**High leakage in Secondary seal => explosive mixture in Secondary vent**	High	No	**High**

Bearing Buffer Separation Air design Review

In line with discussion carried out with the compressor OEM:

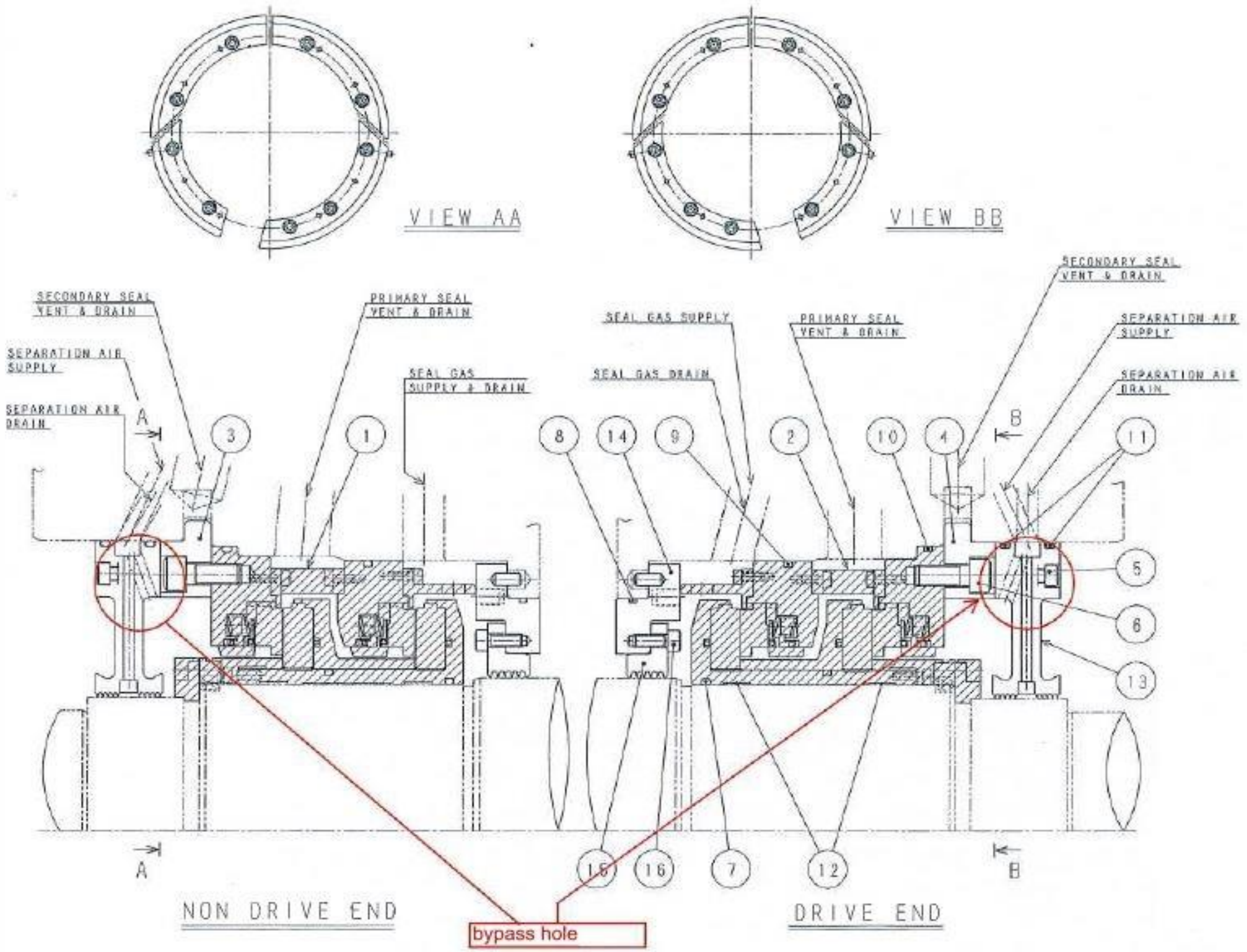
The existing DGS design on the compressor units has been provided with a bypass hole/port in the separation air labyrinths of the secondary seal housing on both ends of Dry Gas Seals. The purpose of this by-pass hole is to keep a minimum of 25 times of air flow against the secondary leakage mass flow rate into the secondary seal vent cavity in order to prevent the creation of mixed explosive gas so as to ensure that the gas to air mixture is kept below 50% of the lower explosive level (LEL) of the gas in order to create a "LEAN SYSTEM".



Bearing Buffer Separation Air design Review

The available bearing buffer separation air design would work:

- As long as the required flow rate of the bearing buffer separation air is ensured, below 50% LEL can be achieved during normal operation/And
- As long as the Secondary seal is intact and in a perfect healthy condition. The situation, in case of secondary seal failure, is not considered for the present bearing buffer separation air design by the OEM. The required flow rate of the bearing buffer separation air is based on the guaranteed leakage rate when the secondary seal is healthy.
- However, Secondary DGS is not instrumented/monitored.



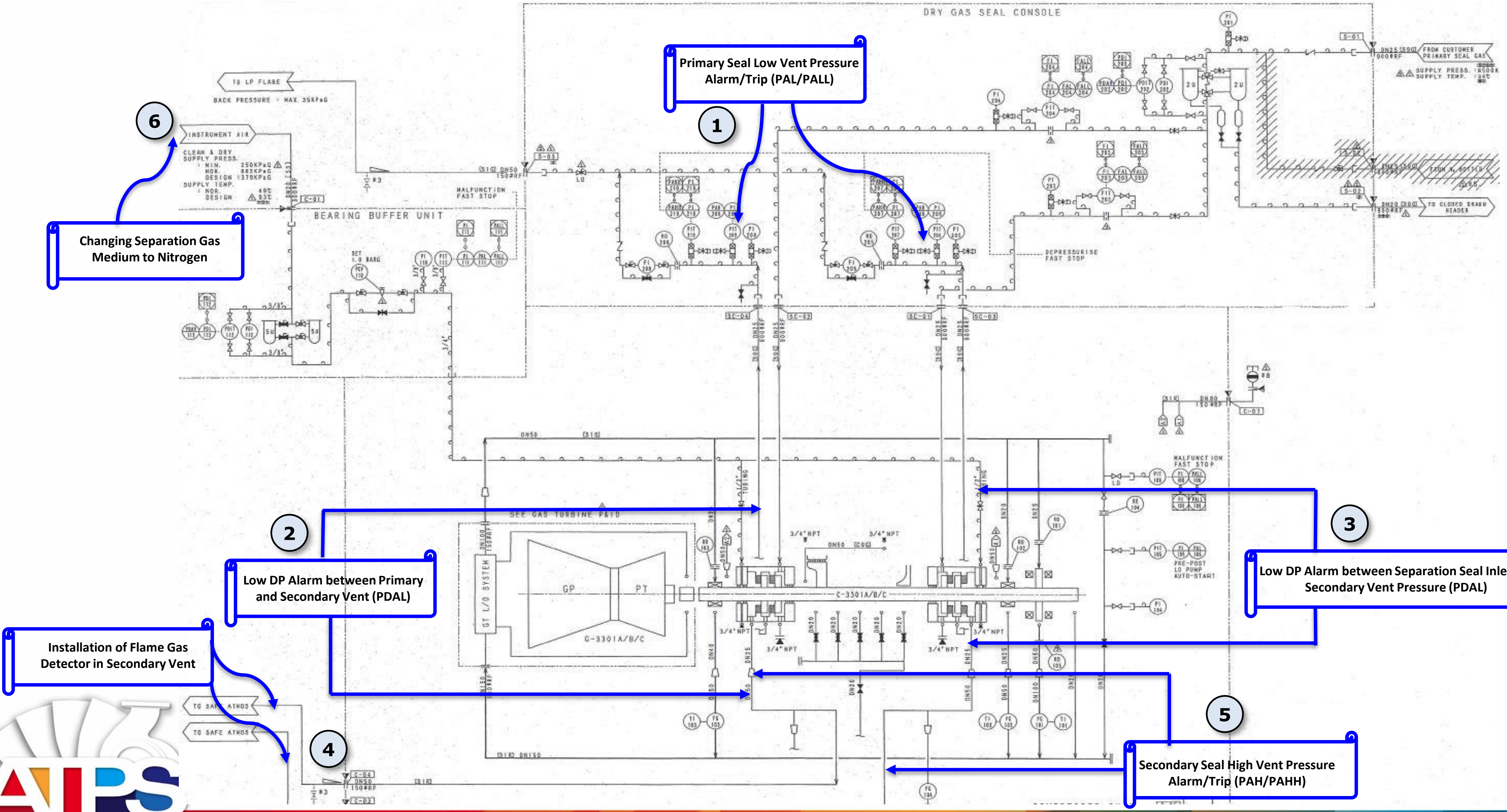
Engineering Study conducted with DGS OEM

- A detailed site survey along with an Engineering study was conducted along with DGS OEM to put forth solutions needed to mitigate the residual risks to ALARP levels.

- Following mitigation solutions were proposed for consideration and evaluations to detect any degradation in Secondary seal health:

  1. Provision of low-pressure alarm in the primary vent line
  2. Provision of low DP Alarm between Primary vent & Secondary Vent
  3. Provision of low DP Alarm between Separation seal inlet and Secondary Vent Pressure
  4. Installation of Flammable Gas Detectors in the Secondary Vent lines
  5. Secondary Seal Vent Pressure Monitoring
  6. Changing Separation Gas Medium to Nitrogen

Mitigation Solutions Proposed-Schematic



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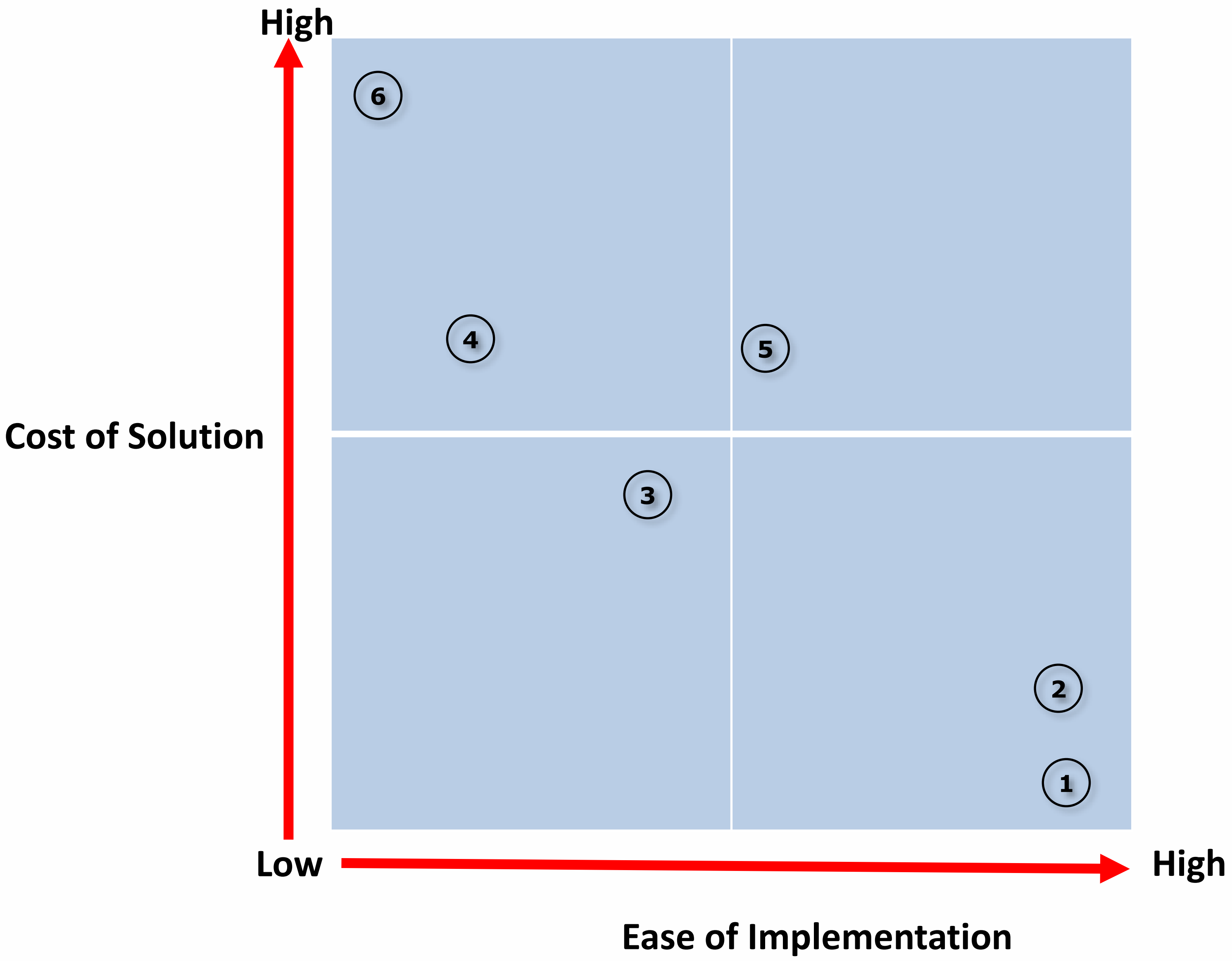
Mitigation Solutions Analysis

Accordingly, a detailed techno-commercial evaluation was conducted for all the proposed mitigation solutions in terms of Cost vis-à-vis Ease of implementation



The Final Solutions

Taking into consideration all the factual information including;

- ✓ DGS Seal System Risk Assessment study,
- ✓ Current bearing buffer separation air design by Compressor OEM,
- ✓ Detailed discussion conducted with both DGS OEM & Compressor OEM, and
- ✓ DGS OEM Site Survey Engineering Study

And in order to monitor the secondary seal health condition, as per the Mitigation solutions Cost vs Doability analysis carried out, the following 02 techno-commercial solutions were agreed upon and implemented to ensure continuous safe operation of the Booster Compressors DGS system namely:

1. **Provision of Low Pressure Alarm in the Primary Vent Line** to help in predicting the condition of the Secondary seal as well as the Process side Labyrinths seals.
2. **Provision of Low DP Alarm between Primary Vent and Secondary Vent** in order to determine the condition of the secondary seal so that proactive replacement action can be taken, in case the secondary seal is not in a perfect healthy condition which may result into creation of explosive gas mixture in the secondary vent line.

Mitigation Solutions Implemented

① **Provision of Low Pressure Alarm in the Primary Vent Line**

Design Data	
Primary Seal Guaranteed Leakage rate (Dynamic)	78 SLPM
Primary Seal Expected Leakage rate (Dynamic)	52 SLPM
Secondary Seal Guaranteed Leakage rate	5 SLPM
LP Flare Header Pressure (Max)	35 kPag
Orifice Size (in PV line)	2.5 mm
PV Line size	DN 25 (1”)
Specific gravity of gas	0.758
Seal Gas Supply temperature	39 deg C

Site Operating Data	
PV Flow (FI 205/208)	2.0 ~ 2.1 Kg/hr (36 SLPM)
PV Pressure @ Orifice	22 ~ 24 kPag (calculated)

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Low Alarm Setting - Primary Vent Pressure	
PV Flow (~ 50% of Operating Flow)	1.6 Kg/hr (29 SLPM)
PV Pressure @ Orifice (PAL)	**13 kPag (Calculated)**

PV = Primary Vent
SV = Secondary Vent

Mitigation Solutions Implemented

② Provision of Low DP Alarm between Primary Vent and Secondary Vent

Since the secondary vent is connected atmosphere, the DP across the PV and SV during normal condition, will be same as pressure at the upstream of orifice in PV which is calculated as 22 ~ 24 kPag.

Low DP alarm set-point (in case of secondary seal failure) is set at 10 kPag based upon the 13 kPag value set for primary vent low pressure alarm. A difference of 3 kPag is provided in the set points between DPT and PIT. This is to ensure and re-assure that bulk of the primary seal gas is indeed finding its way to secondary seal resulting in drop in pressure in the primary vent.

Site Operating Data	
PV Pressure @ Orifice	22 ~ 24 kPag (calculated)

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Low DP Alarm Setting – Primary/Secondary Vent	
PV Low Pressure Alarm	13 kPag
DPT Alarm (DPAL)	**10 kPag**

The seal gas flow corresponding to this alarm set point is based on 50% of the normal flow.

Results

The cost-effective solutions implemented ensured continuous safe operation of the Booster Compressors DGS as well as in mitigating the residual risks within ALARP levels.

Lessons Learnt

- Monitoring/safeguarding of the Secondary seal is mandatory to ensure a healthy back-up to the main Primary seal.
- Separation gas systems with N2 injection are preferred because they consume much less air (smaller air compressors) and can offer the possibility of implementing very precise and reliable monitoring systems. N2 membranes are reliable, compact and not very expensive. However, this is not always possible in brown fields.
- In the case of unavailability of N2 injection (old installations or not possible to have N2 as in the majority of the unmanned compression stations), the air injection has to be designed to ensure that the secondary vent is lean. It is recommended to have 30% LEL at guaranteed secondary seal leakage so as to allow for a degradation to 3 times guaranteed leakage before having an explosive mixture in the secondary vent.
- In such scenarios, various monitoring systems could be implemented with different degree of precision/reliability.
- In this present case, the solution adopted was to have a DP between vents and configuring a low pressure alarm on primary vent. This system with the current proposed settings can detect degradations in the secondary seal.

Thank you for your passion !

Back-up

Mitigation Solutions Analysis Details

1 Provision of Low pressure alarm/trip in the primary vent line

This solution of monitoring the secondary seal via monitoring primary vent pressure introduces a backpressure in the primary vent, which in turn applies pressure to the secondary seal. In the event of the secondary seal failure, the pressure in primary vent cannot be maintained as a portion or all of the primary vent flow passes through the secondary seal. Primary vent pressure falling below a predetermined value indicates a possible problem with the secondary seal. This solution was selected and implemented.

2 Provision of Low DP Alarm between Primary vent & Secondary Vent

This solution introduces a DP transmitter to measure the DP between the Primary and Secondary vent, where the HP side of the transmitter shall be connected to the Primary vent and LP side to the Secondary vent. Since the Secondary vent is connected to atmosphere, the DP across the Primary vent and Secondary vent during normal condition, will be same as pressure at the upstream of orifice in Primary Vent. A low DP alarm would indicate a deteriorated secondary seal. This solution was selected and implemented.

3 Provision of Low DP Alarm between Separation seal inlet and Secondary Vent Pressure

Under this solution, a DP transmitter is introduced to measure the DP between separation seal inlet and secondary vent pressure, where the HP impulse line of the transmitter shall be connected to separation seal inlet and LP connection to the Secondary Vent. A low DP alarm would indicate a worn out secondary seal.

However, since this DP would be very small to have any reasonable measurement, this solution was not selected. Moreover, it may not provide an accurate picture, in case there are changes to labyrinths condition (e.g. worn-out or otherwise).

Mitigation Solutions Analysis Details

④ Installation of Flammable Gas Detectors in the Secondary Vent lines

Under this solution, gas detectors are installed to measure hydrocarbon content in the secondary vents. Detection of process gas presence in the secondary vents may identify a secondary seal failure. This solution was not considered due to inherent unreliability issues involved with flammable gas detectors for the intended application. Furthermore, the gas detectors would also need higher degree of maintenance efforts including periodic calibration required resulting in increased expenditure.

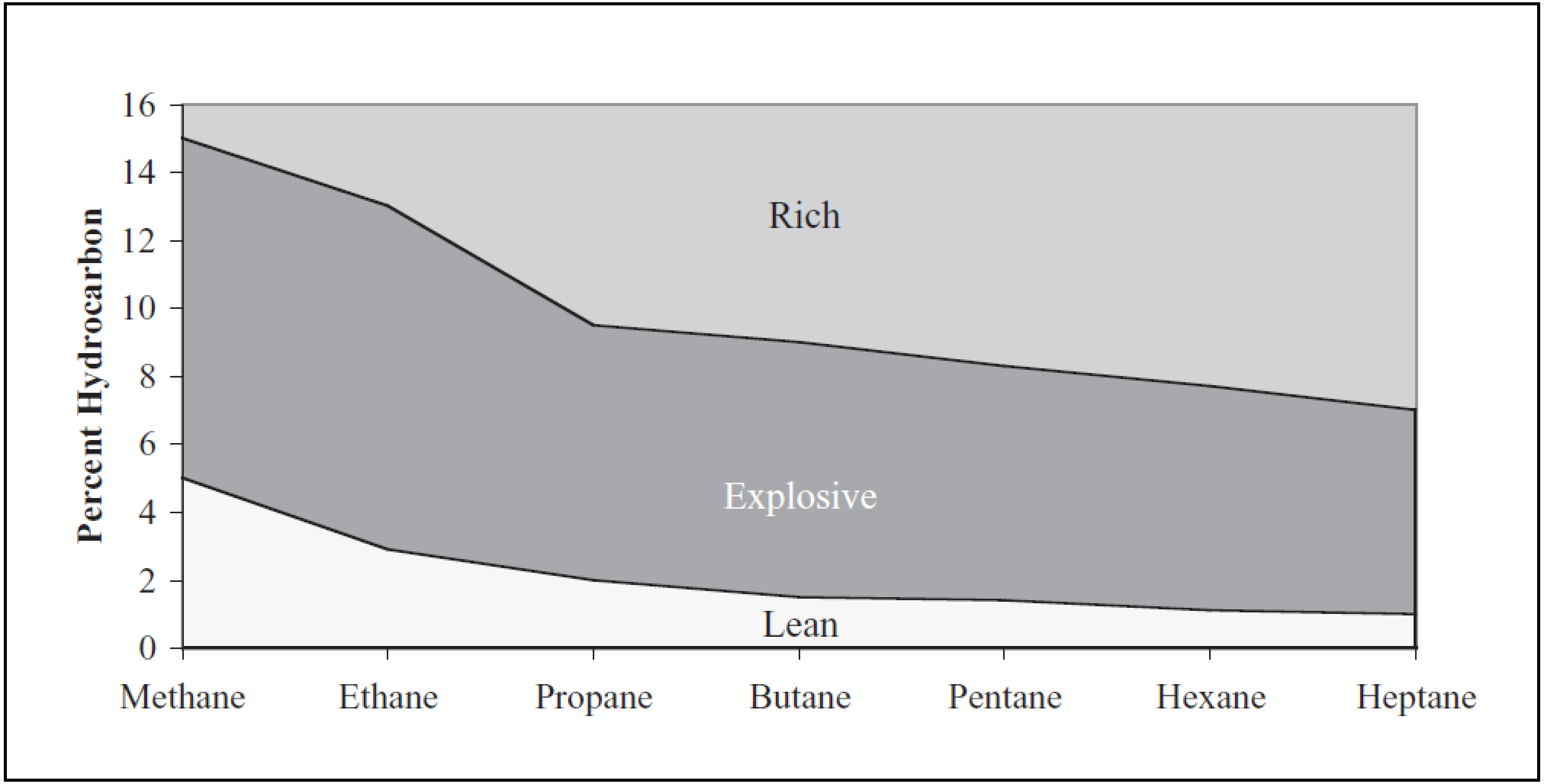
⑤ Secondary Seal Vent Pressure Monitoring

Under this solution, a pressure transmitter is installed in the secondary vent line. If the secondary seal fails, the flow in the secondary vent will increase by the amount of primary vent flow passing through the secondary seal. Increased flow would raise the pressure in the secondary vent indicating a possible problem with the secondary seal. However, this solution was not considered as practically, the pressure increase in unrestricted secondary vent lines is undetectable. The only case when the secondary seal failure can be reliably diagnosed by this option is when the secondary seal failure has been preceded by the primary seal failure whereby the process gas is flowing into the secondary vent.

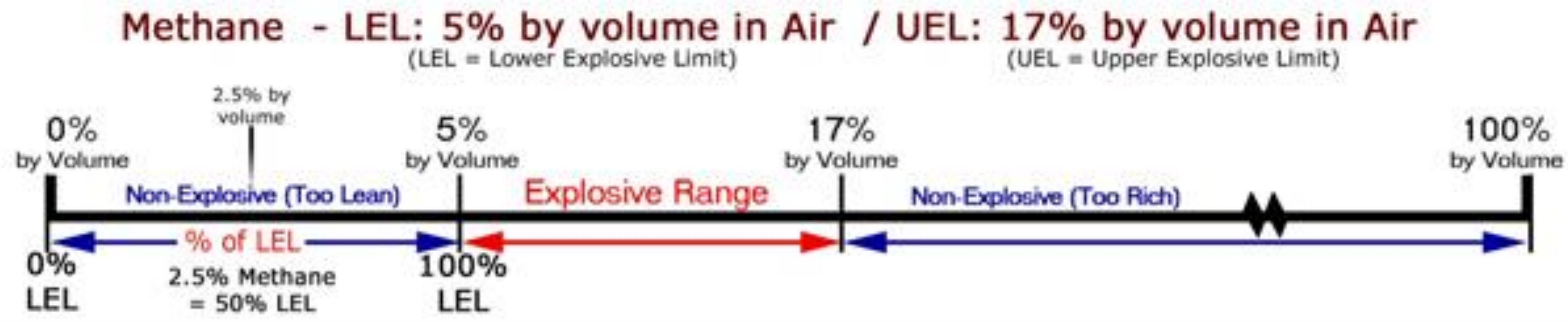
⑥ Changing Separation Gas Medium to Nitrogen

Changing the Separation gas medium from Air to Nitrogen. This solution would avoid the possibility of creating any explosive mixture in the secondary vent. However, this solution was dropped due to the extensive cost involved for a brown field modification.

Explosive Mixtures of Hydrocarbon Gases



Lean (LEL) and Rich (UEL) Environment



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Questions?