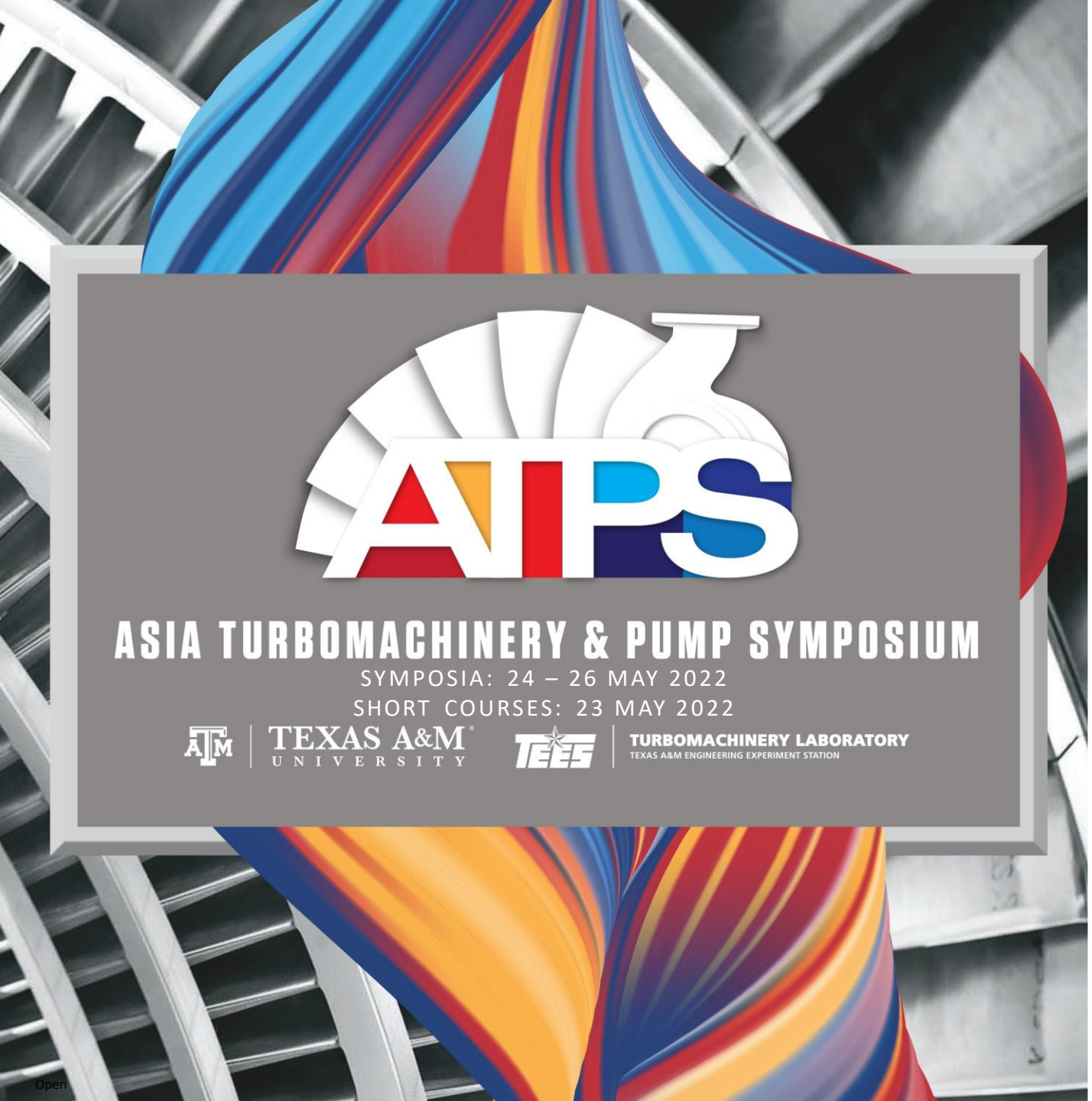


Catastrophic Mechanical Seal Failure Leading to Loss of Primary Containment (LOPC)

Mohd Faizal Mohamed – PETRONAS
Khairil Ikhwan Abdul Rahman – PETRONAS

PETRONAS

Authors

Mohd Faizal Mohamed

Staff Rotating Engineer in Integration, Value & Assurance Division at Petronas Carigali. His responsibilities include reliability improvement, maintenance excellence, root cause failure analysis, and engineering review. He is based in Malaysia and has over 15 years of rotating machinery experience.

Khairil Ikhwan Abdul Rahman

Senior Rotating Engineer in Peninsular Malaysia Asset at Petronas Carigali. His responsibilities include equipment monitoring & analysis, reliability improvement program and value driven maintenance. He is based in Malaysia and has 9 years of rotating machinery experience.

Abstract

- Usage of mechanical seal is widely used in rotating equipment especially pump. It prevents fluid or product of the pump from leaking to atmosphere. Consequence of seal leaking will be more critical if the product itself is hazardous.

- Generally, mechanical seal for pump used for hazardous product such as hydrocarbon will be classified as safety critical element (SCE) which require specific assurance task to ensure it is always operating within acceptable criteria and condition.

- This case study will be detailing out situation whereby poor preservation of spare mechanical seal can cause catastrophic failure and subsequently leaving hydrocarbon release to environment. Presence of moisture in the mechanical seal assembly lead to high possibility for slip stick to happen especially at seal faces. Subsequently, both stationary and rotating faces tend to rotate together during pump startup and cause significant impact damage when contacted with anti-rotation pin slot.

- Several mitigations & best practices were outlined on how to handle mechanical seal storage and preservation with the input from various parties including seal original equipment manufacturer (OEM). Adhere to proper preservation and assurance task will sustain the process safety barrier related to the process containment on rotating equipment.

Executive Summary

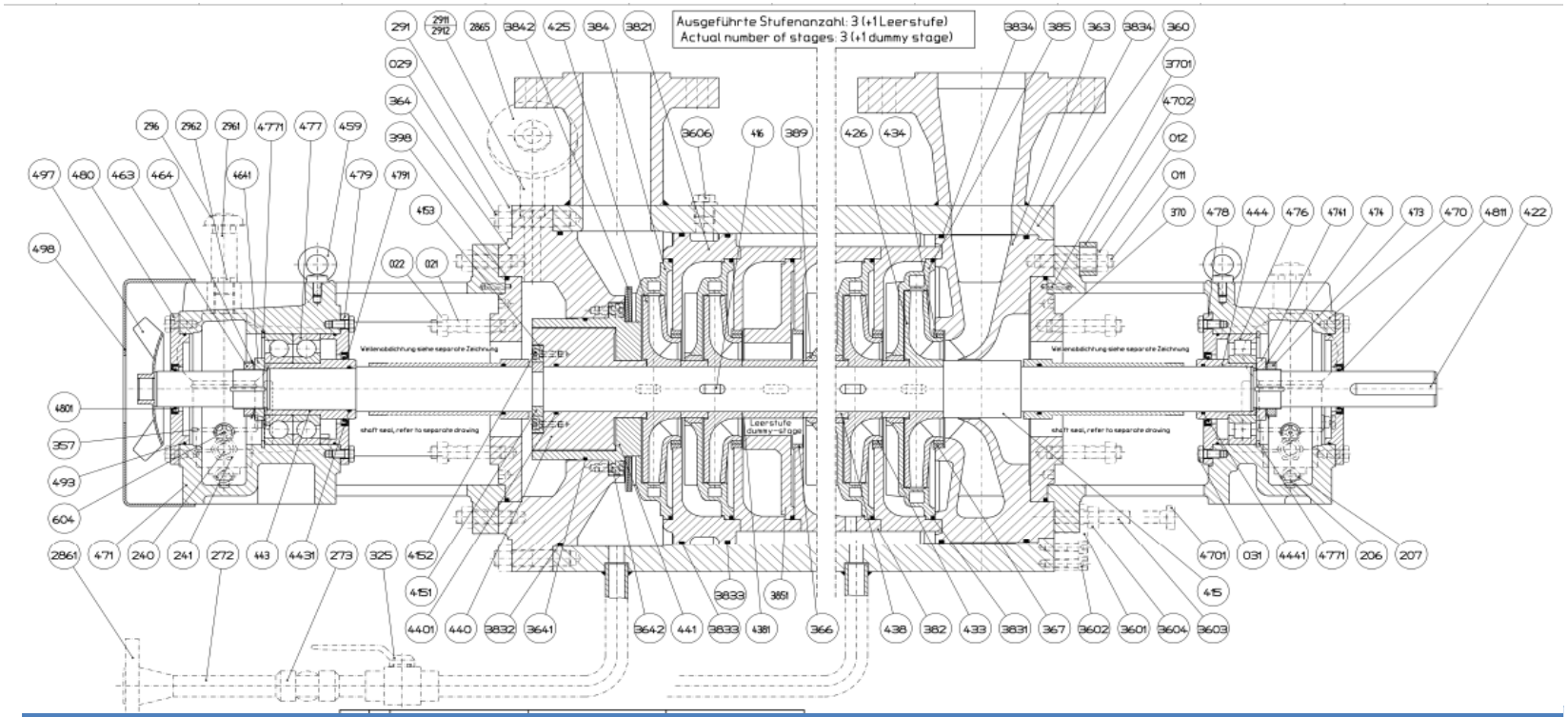
- The purpose of this case study is to present 2 failure mechanisms which have contributed to catastrophic mechanical seal failures leading to loss of primary containment (LOPC) at condensate transfer pumps (CTP). The impact of LOPC is more severe if the product itself is hazardous to people, asset & environment.

- Mechanical seal failure may be contributed by many factors such as poor installation, misalignment of seal face cascaded from pump vibration, dry running, over compression, thermal shock or expansion, poor barrier fluid quality, etc.

- For case#1, catastrophic seal failure occurred due to presence of free water and sludge in seal barrier fluid which has caused water vaporization due to high heat generation and low boiling point. The thin barrier fluid film between seal faces could not be sustained leading to face-to face contact causing chipping of seal face.

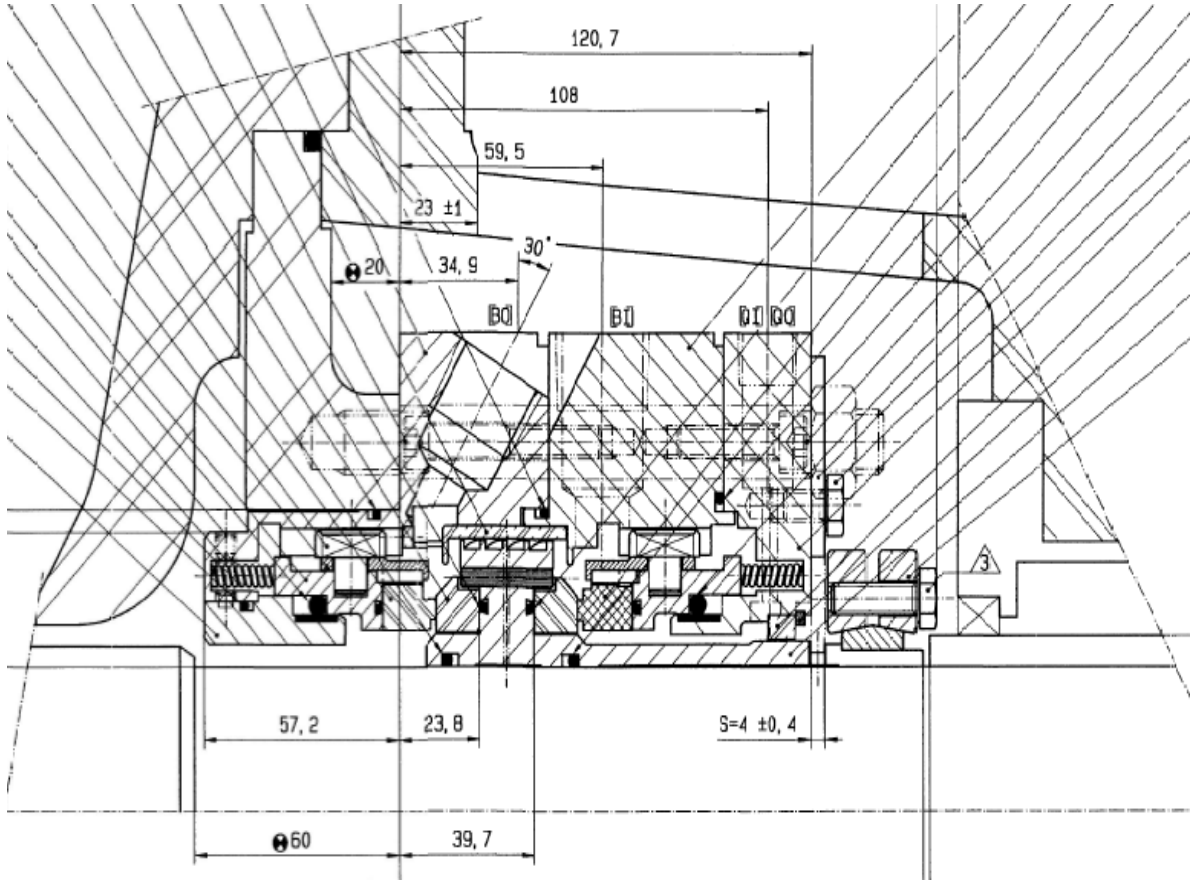
- Meanwhile for case#2, another failure mechanism was due to poor preservation of spare mechanical seal which has caused the moisture from atmosphere to accumulate at the seal face, creating a slip stick condition and initiated a hairline crack on seal face pin slot. Due to the high torque from the pump, the hairline crack propagated through the pin slot at the outboard rotating seal face. The outboard seal cracked, leading to anti-rotating pin dislodged and subsequently hammered the inboard seal face.

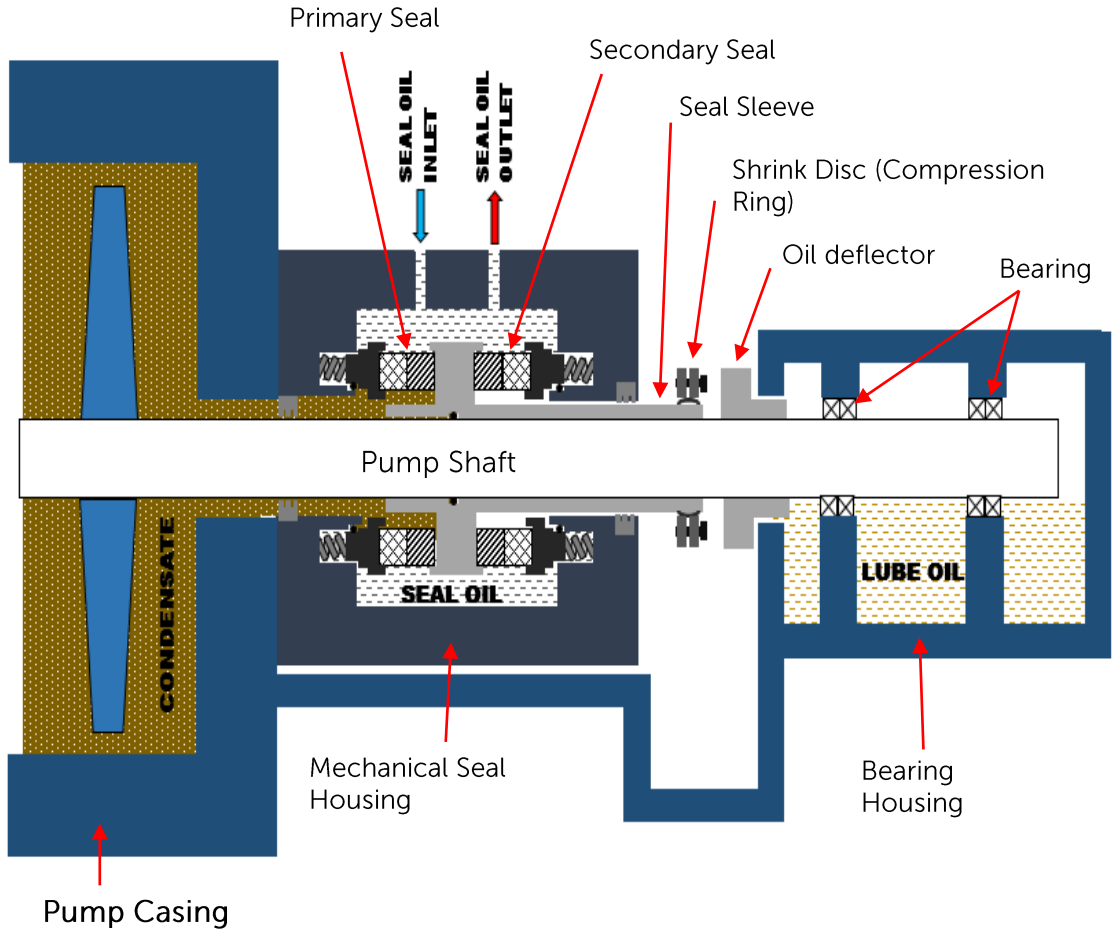
Equipment Overview (Pump)



Description	Data
Pump Type	Horizontal centrifugal (4 stages + 1 Dummy)
Suction Pressure	73.5 barg
Discharge Pressure	87.5 barg
Mechanical Seal Type	Pressurized Dual seal
Barrier Fluid Pressure	88.2 – 95.1 barg
API Seal Piping Plan	API 53 modified
Barrier Fluid	ISO VG XX

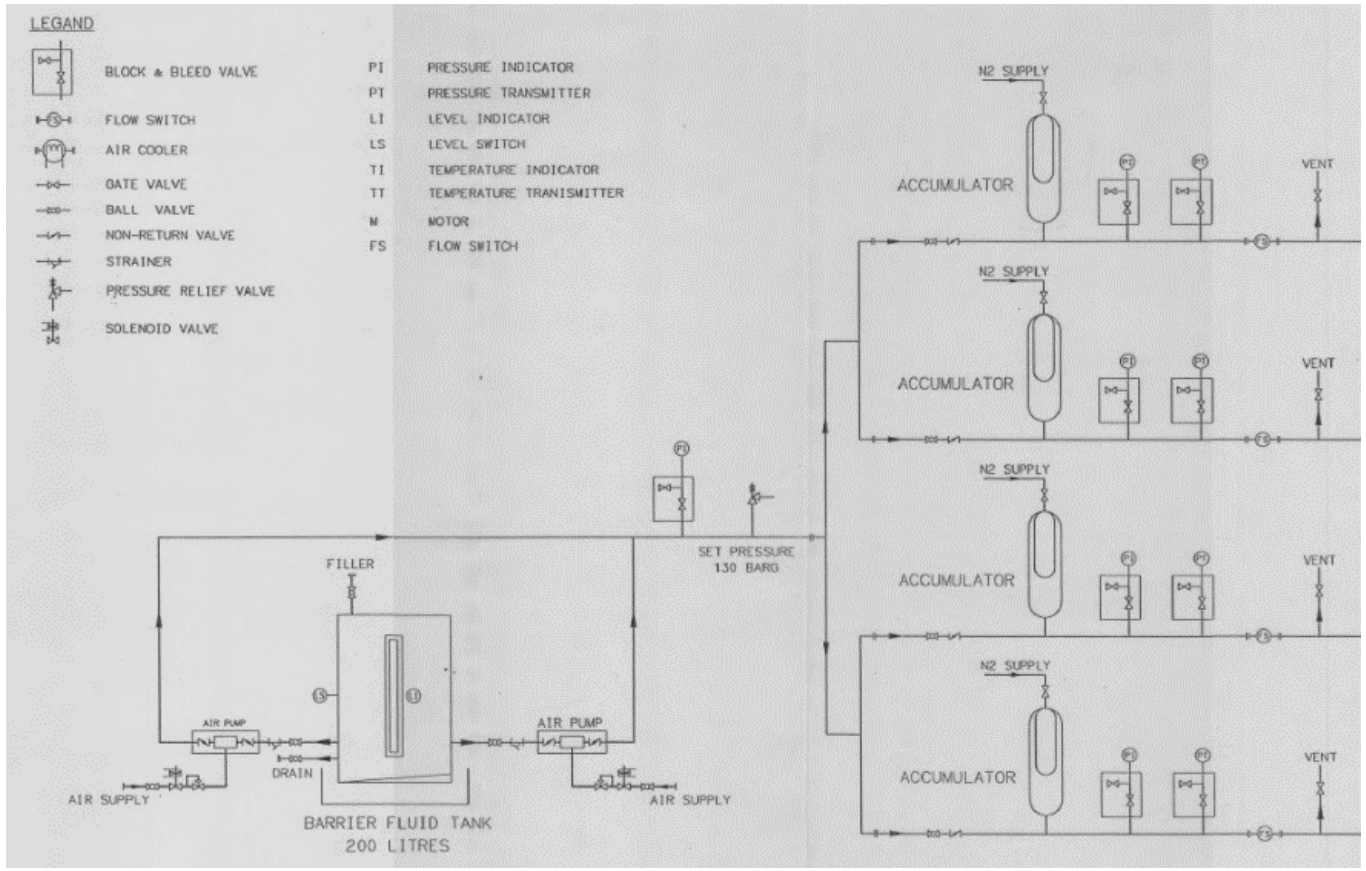
Equipment Overview (Mechanical Seal)



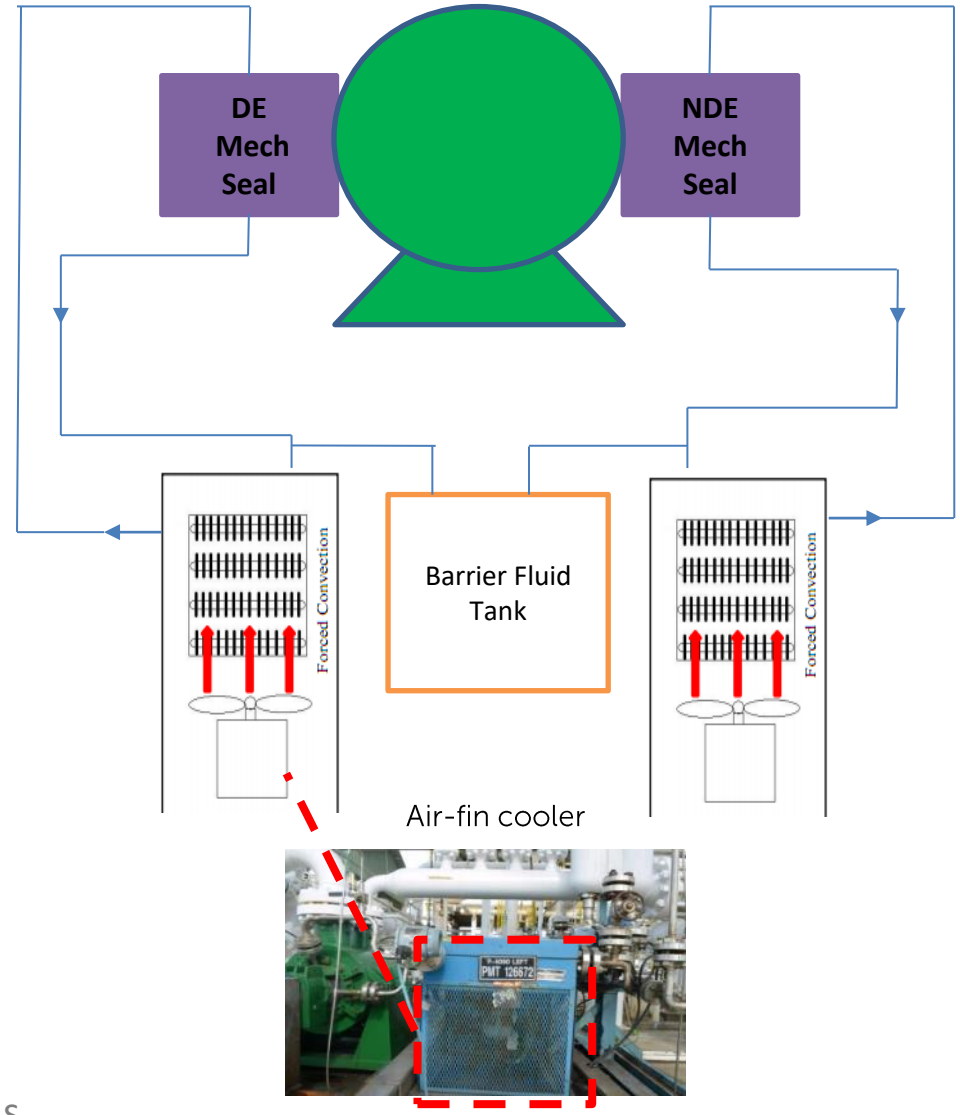


Mechanical Seal Cross Section

Equipment Overview (Mechanical Seal Auxiliary System)



Seal auxiliary support system

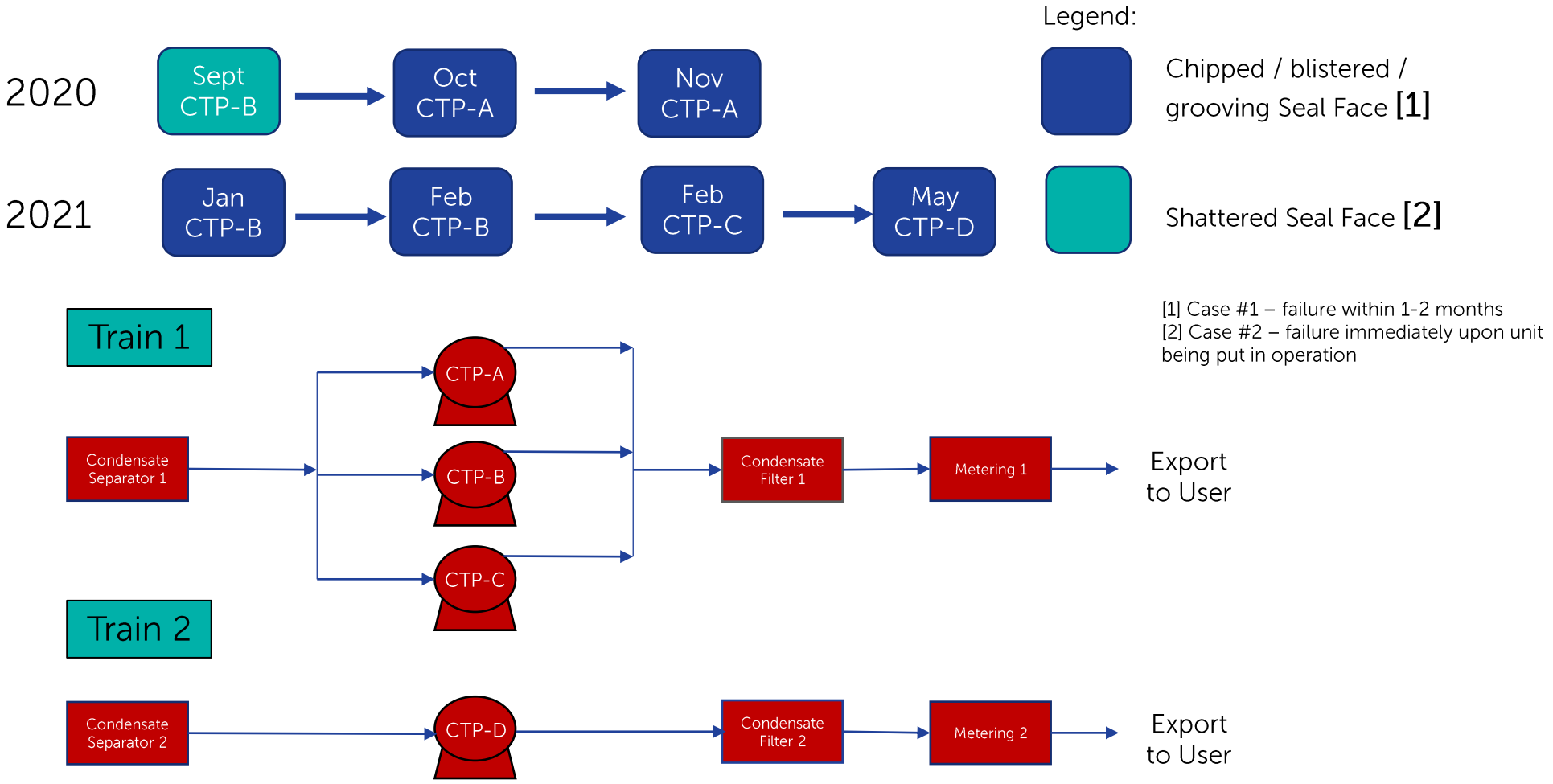


Arrangement on the auxiliary system:

1. Common barrier fluid tank to serve all the pumps
2. Auto make-up pump to maintain the seal pressure
3. Equipped with seal protection instrumentation / devices
4. Dedicated accumulator & air fin cooler for each seal i.e. DE & NDE

Background

Condensate Transfer Pumps at an onshore production facility, experienced multiple mechanical seal leaks in 2020 and 2021 leading to high replacement cost and LOPC (release to atmosphere)



Typical Event Snapshot During Mechanical Seal Catastrophic Failure

DCS event summary during mechanical seal catastrophic failure which led to LOPC

Seal protection as following:

a) Seal flow High-High (HH)
b) Seal pressure Low-Low (LL)
c) Seal temperature High-High (HH)

- Pump Trip Status to DCS due to seal protection system triggered
- Pump STOP status to DCS

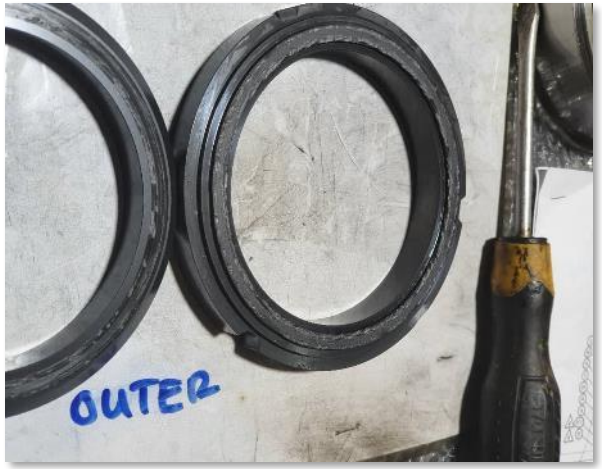
Acknowledge	LC2044	PVLO	HIGH	V-2030B	64		1	31
Alarm	UA2040B	PMP TRIP/FAULT						
Alarm	GBS2040B	OFFNORM	HIGH	PUMP STOPPED	20		1	31
Return To Normal	H52040B	P-2040B PUMP RUNNING						
Alarm	FC2041	PVLL	EMERGNCY	DISCHARGE FLOW	20		1	31
Alarm	FC2041	PVLL	EMERGNCY	DISCHARGE FLOW	20		1	31
Return To Normal	UA2040B	P2040B PMP TRIP/FAULT						
Alarm	UA2040B	P2040B PMP TRIP/FAULT						
Acknowledge	UA2040B	P2040B PMP TRIP/FAULT						
Acknowledge	FC2041	PVLL	EMERGNCY	DISCHARGE FLOW	20		1	31
Acknowledge	FC2041	PVLL	EMERGNCY	DISCHARGE FLOW	20		1	31
Acknowledge	GBS2040B	OFFNORM	HIGH	PUMP STOPPED	20		1	31
Acknowledge	UA2040B	P2040B PMP TRIP/FAULT						
Acknowledge	FC2041	PVLL	EMERGNCY	DISCHARGE FLOW	20		1	31
Acknowledge	FC2041	PVLL	EMERGNCY	DISCHARGE FLOW	20			
Acknowledge	GBS2040B	OFFNORM	HIGH	PUMP STOPPED	20			
Alarm	UA2040B	P2040B PMP TRIP/FAULT						
Alarm	FC2041	PVLL	EMERGNCY	DISCHARGE FLOW	20			
Alarm	FC2041	PVLL	EMERGNCY	DISCHARGE FLOW	20			
Alarm	GBS2040B	OFFNORM	HIGH	PUMP STOPPED	20		1	31
Return To Normal	UA2040B	P2040B PMP TRIP/FAULT						
Return To Normal	P14633	COND. METERING OUTLET						
OperatorAction	FC2011	BADPV	LOW	DISC FLOW PMP 2	20		1	31
Alarm	XZAS8036	XZS-8036 TRIP / FLT						
Return To Normal	XZAS8036	XZS-8036 TRIP / FLT						
Alarm	XZAS8036	XZS-8036 TRIP / FLT						
Return To Normal	XZAS8036	XZS-8036 TRIP / FLT						

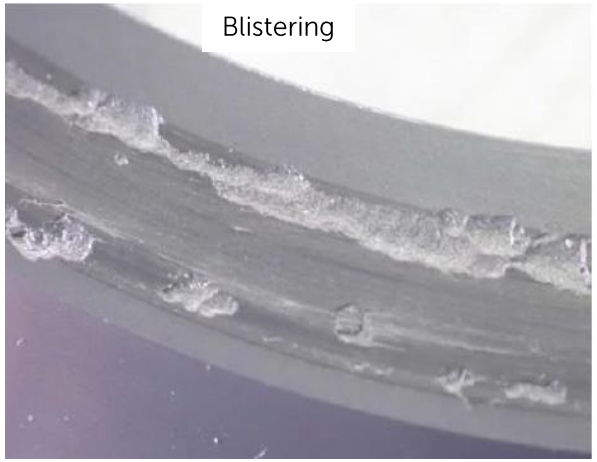
- XZAS8036: Detection once LOPC release post unit tripped with mechanical seal catastrophic failure

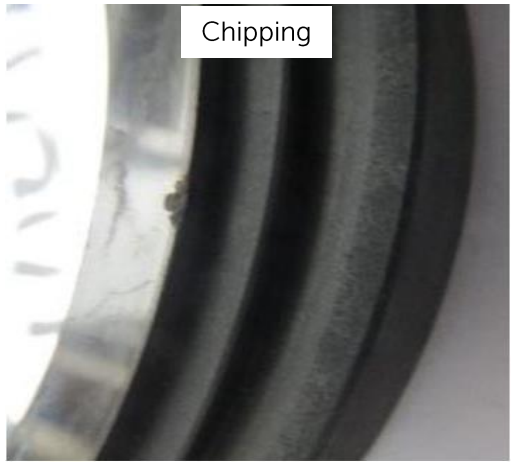
Case#1: Mechanical Seal Catastrophic Failure

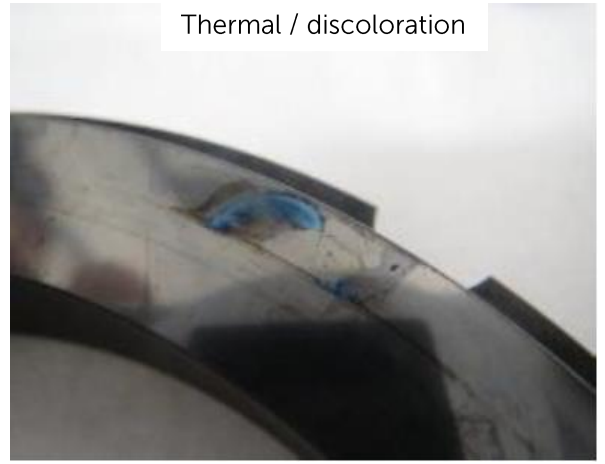
Findings on mechanical seal post disassembly:

1. Failure occurred within 1-2 month post installation & unit running
2. Internal parts showed seal face chipping/discoloration/blistering in most failure events





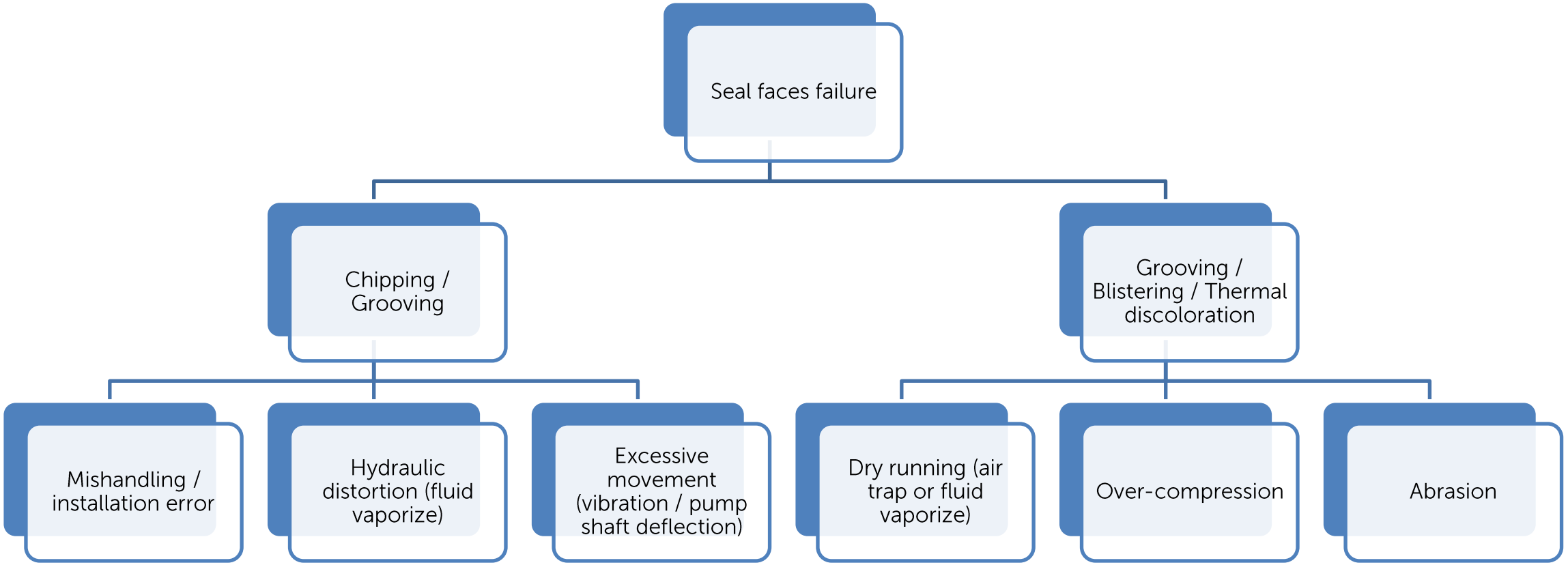




Some of photos on seal faces with following observation

- Chipping
- Blistering
- Thermal discoloration
- grooving

Possible Causes of Seal Face Failure

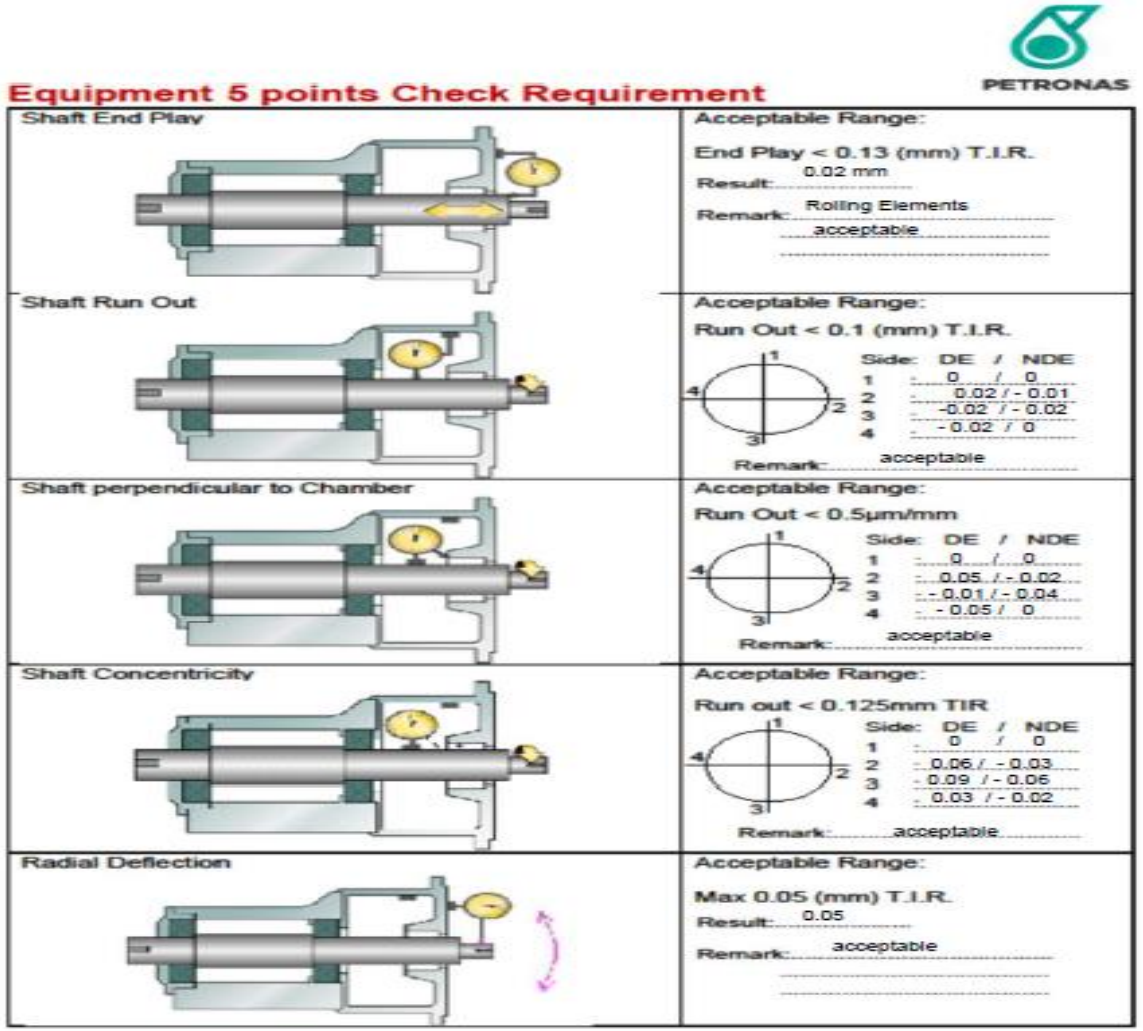


Possible Causes Elimination Process

Cause Level 1	Sub Cause Level 2	Sub Cause Level 3	Sub Cause Level 4	Findings
Chipping during seal installation	Mishandling	Installation Error	N/A	Installation as per procedure and meet specification
Excessive shaft run-out	Shaft deflected causing seal face not perpendicular to the shaft axis	Seal face has high load concentration on edge of face : causing nose worn out	N/A	Seal face showed no sign of nose worn out 5-point check meet specification
Hydraulic imbalance	Seal face slamming	Pump Cavitates	Cavitation bubbles cause erratic sealing	No signs of cavitation on pump such as pressure fluctuation and high vibration/abnormal sound
		Fluid vaporizes at seal face	High temperature at mating face: vaporize the barrier fluid at mating face Air entrainment on piping: clogged route, reduce flow	Barrier fluid temperature is 130-160F during running Bleed at barrier fluid lines to remove entrained air prior to startup Barrier Fluid tank contains free water

1(a) Verification & Elimination Process – Alignment & Vibration

NO	DESCRIPTION OF TASK ACTIVITY	TASK RECORD YES	TASK RECORD NO	REMARKS/ FINDINGS
A	**MECH. SEAL REMOVAL**			
1	Depressurize seal system or barrier fluid	X		
2	Check & record pump to motor aligment (as found)		X	
3	Check & record DBSE before remove coupling hub	X		DBSE : 256.13 mm
4	Lock the mechanical seal setting plate	X		
B	**MECH. SEAL INSTALLATION**			
1	Check & record 5 points check (DE & NDE)	X		Refer 5 plonts check checklist
2	Record Shaft dimension (OD) at bearing & mech seal location	X		Shaft OD : Bearing Seat 69.99 mm Mechanical Seal Seat 69.99 mm
3	Record Mechanical Seal Sleeve ID	X		Mechanical Seal Sleeve ID : 70.03 mm
4	Tighten mech. seal gland follow with tightening sequence & torque value	X		
5	Tighten shrink disc follow with tightening sequence & torque value. 50% - 100% - 100%	X		Tightening Sequence : Rotational / Criss-Cross Torque Value : 20 Nm (using feeler gauge 1.5 mm / 3.5 mm)
6	Check & record DBSE before couple coupling	X		DBSE : 256.13 mm DBHE: □272.03 mm
7	Perform & record pump to motor aligment	X		Attach aligment report
8	Uniock the mechanical seal setting plate	X		
9	Pressure up mechanical seal barrier fluid & visual check. Record initial Pressure	X		DE : 90 Bar NDE : 90 Bar
C	**PUMP START UP PARAMETER READING**			
1	Mechanical seal barrier fluid pressure DE & NDE. (Initial, 30m, 1 Hour, 3 Hour)	X		DE Initial Reading : 90 Bar 30m: 90 Bar After 1H 90 Bar 3H n/a Bar
2	Mechanical seal barrier fluid temperature DE & NDE (Initial, 30m, 1 Hour, 3 Hour)	X		DE Initial Reading : 50 °C 30m: 60 °C After 1H 65 °C 3H n/a °C
3	Suction and discharge pump pressure (Initial, 30m, 1 Hour, 3 Hour)	X		DE Initial Reading : 80 Bar 30m: 80 Bar After 1H 80 Bar 3H n/a Bar
4	Record balance line Pressure. (Pump Discharge Casing to Suction Piping)	X		Balance Line Pressure : 80 Bar
5	Observe leaking (acceptable leakage rate 4 drops per min.)	X		Leak Rate : no leaks observed drops/min
D	**Summary of Findings**			



Seal installation within specification & requirement– normal

1(b) Verification & Elimination Process – Alignment & Vibration




Locations	Point ID	Point Description	Overall Vibration Measurements			Units (RMS)
			1130AM			
Motor NDE BEARING	1H	Horizontal	1.66			mm/s
	1V	Vertical	0.83			mm/s
	1A	Axial	1.00			mm/s
	1P	Peakvue	0.50			G's
Motor DE BEARING	2H	Horizontal	1.57			mm/s
	2V	Vertical	0.64			mm/s
	2A	Axial	1.18			mm/s
	2P	Peakvue	0.58			G's
Pump DE BEARING	3H	Horizontal	1.87			mm/s
	3V	Vertical	1.69			mm/s
	3A	Axial	0.55			mm/s
	3P	Peakvue	0.65			G's
Pump NDE BEARING	4H	Horizontal	2.08			mm/s
	4V	Vertical	1.23			mm/s
	4A	Axial	0.63			mm/s
	4P	Peakvue	1.03			G's

NO.	MACHINE DESCRIPTION	MACHINE ID	June-21	Aug-21	Oct-21	FINDINGS	RECOMMENDATIONS/ACTIONS
11	Condensate	Pump	3	NA	3	• Acceptable vibration with the highest amplitude recorded is **2.4** mm/s rms @**Motor DE** horizontal axis. Acceptable limit < 4.5 mm/s rms. Danger> 7.1 mm/s RMS.	

SEVERITY COUNT					DESCRIPTION
1	HIGH	0	0	0	Perform rectification within **1 MONTH.**
2	MEDIUM	0	1	1	Perform rectification within **2 MONTHS.**
3	ACCEPTABLE	9	9	11	No action required. Continue with normal scheduled maintenance and switching program.
NR	NOT RUNNING	5	3	0	Equipment not running during visit.
NA	NOT AVAILABLE	1	2	3	Equipment not available at site/ OOS during visit.

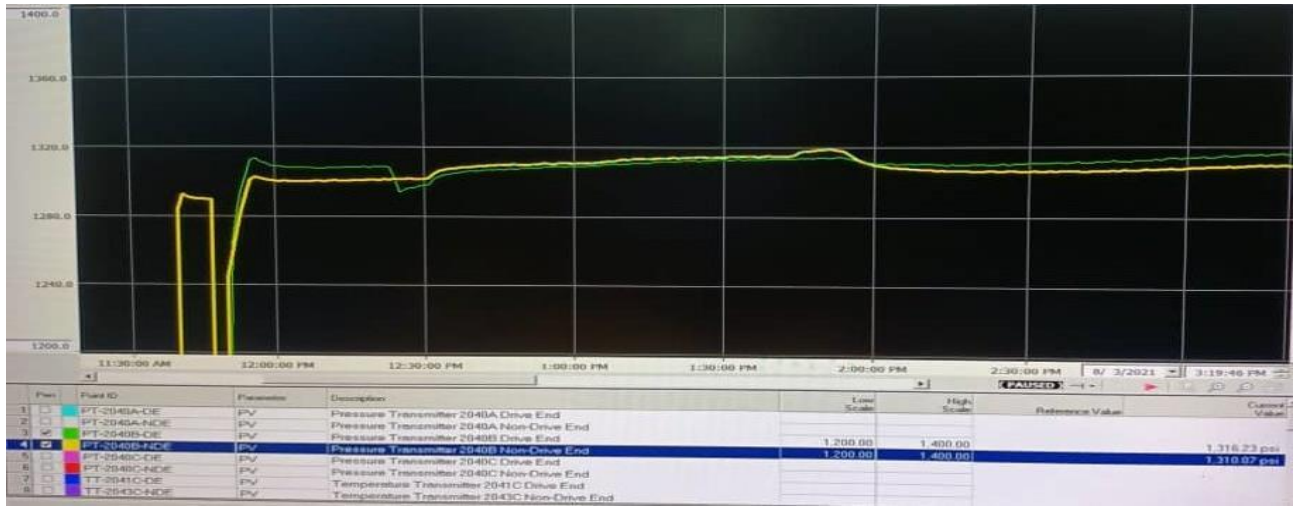
Vibration & alignment result is within specification – normal

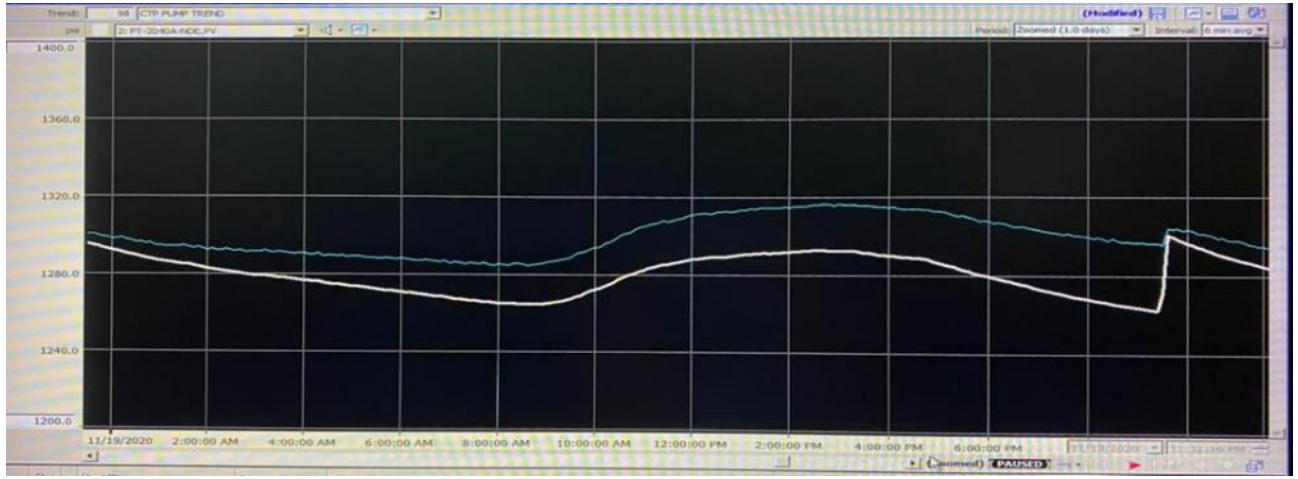
1(c) Verification & Elimination Process – Process Parameters

	EU	Lo-Hi	07:00 – 18:59
Equipment Status			Running Manual
Any abnormalities?			Normal
Any sign of leaking?			No
Are seal/barrier oil level<30%? If YES please top up			No
Any integrity issue?			No
Pressure gauge functioning?			Yes
Any dirt or debris?			No
Discharge pressure	Barg	16.9 – 17.1	90
Flow Rate in KL or Hour	m3/h	105.9 – 106.1	97
Recycle valve opening %	%	0 – 101	30
Tank barrier fluid %	%	30 – 101	90
DE lube oil level in oil pot %	%	50 – 90	80
NDE lube oil level in oil pot %	%	50 – 90	80
Pump strainer inlet pressure	Psi	99 – 301	76
Pump strainer outlet pressure	Psi	99 – 301	76
DE barrier fluid temperature	DegF	0 – 180	152
NDE barrier fluid temperature	DegF	0 -100	102
DE barrier fluid pressure	Psi	1299.9 – 1300.1	1300
NDE barrier fluid pressure	Psi	1299.9 – 1300.1	1300
Ammeter status?			Normal
Housekeeping condition?			Good
Any other findings? If YES please write here			No

Daily basic equipment care (BEC) - normal

- During this repetitive failure, CTP barrier fluid pressure was maintained at around 1280-1380 psi (as per specification)
- Trend of BF Pressure indicate an expected value of BF pressure.
- Reading of seal temperature were also within allowable range (130 – 160F)
- However, the MTBF for the seal as recorded was less than a month after installation when the unit was put back in service.





Parameters was normal before failure event - normal

1(d) Findings on Barrier Fluid Tank

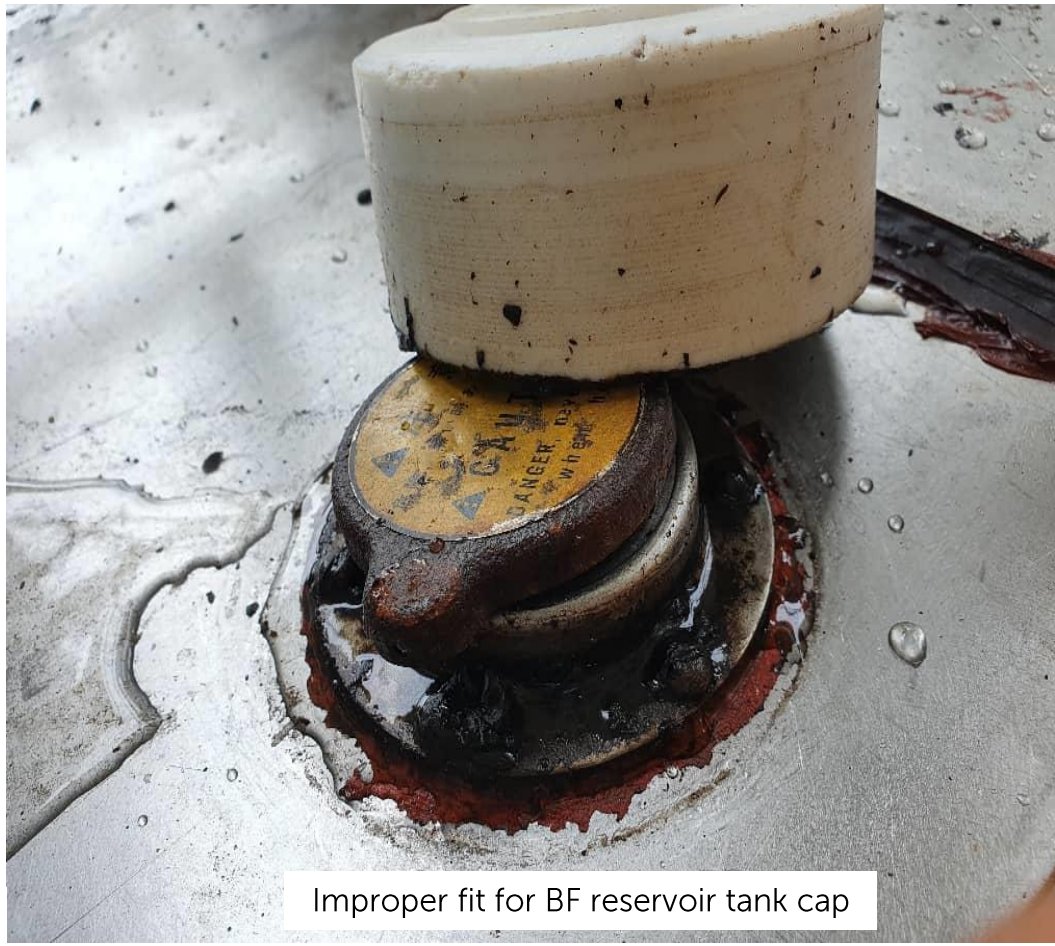
Further investigation at site revealed BF tank has been contaminated with water and sludge, and the tank cap used was not fit for the BF tank

View of BF tank reservoir

BF sample collected at cooler indicated contamination with water

Bleed BF at vent line – present air-lock

BF sample collected bottom of tank with sludge present



Improper fit for BF reservoir tank cap

Case#1: Failure Mechanism Summary

The suspected failure mechanism for 6 of 7 failure cases:

Free water observed at BF Reservoir

Water vaporizing between seal faces due to high heat generation and low boiling point

Increased probability of face-to-face contact of seal faces

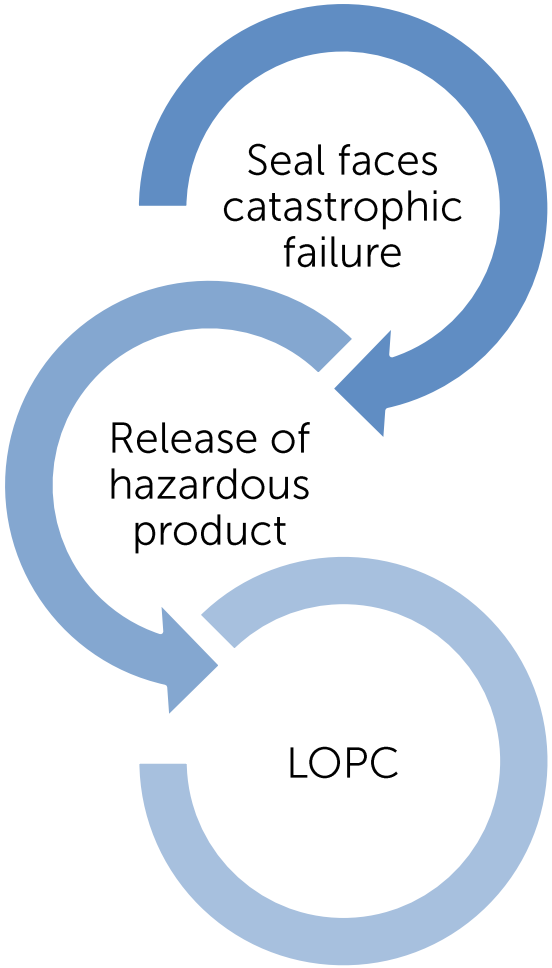
Seal face chipping / thermal discoloration / blistering leading to mechanical seal failure

Sludge & Free water observed at BF reservoir

Water vaporizing between seal faces / abrasive particles

Face to face contact/ abrasive surface to the seal face

Seal face chipping / grooving leading to mechanical seal failure

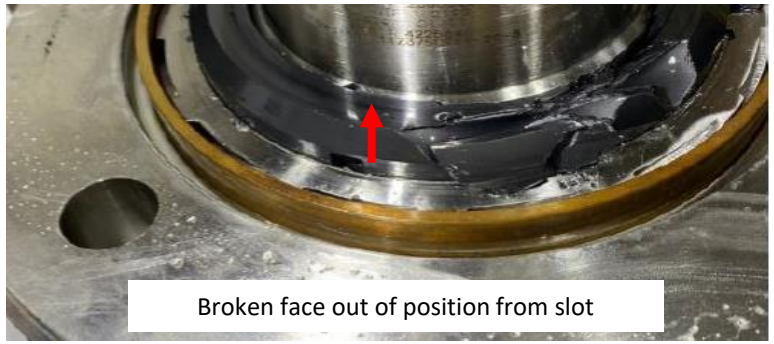


Case#2: Mechanical Seal Catastrophic Failure

Findings on mechanical seal post disassembly:

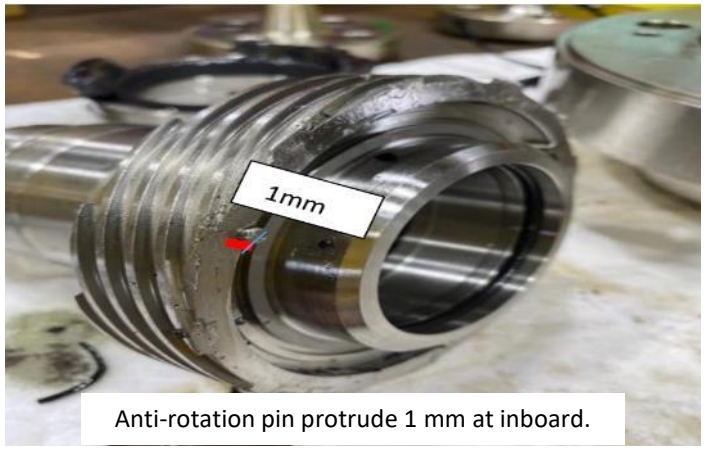
1. Failure occurred within minutes after pump running post seal installation
2. Seal faces broken into pieces/shattered. Broken point started around pin slot

NDE mechanical seal inboard seal face broken & shattered

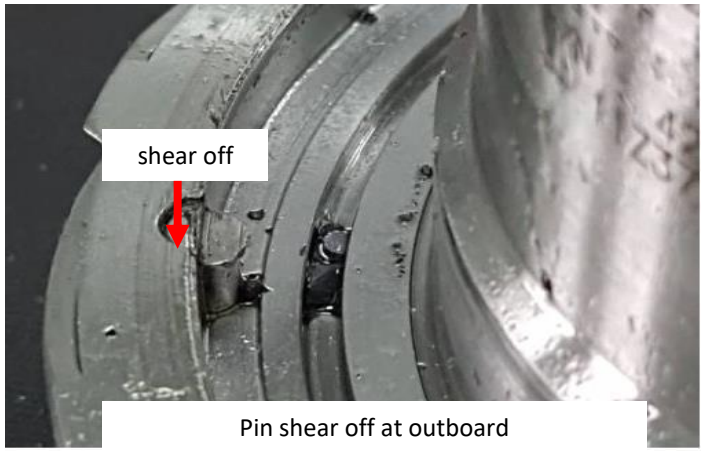


Broken face out of position from slot

Knocking / hammering damage at the back of mechanical seal, near pin slot



Anti-rotation pin protrude 1 mm at inboard.



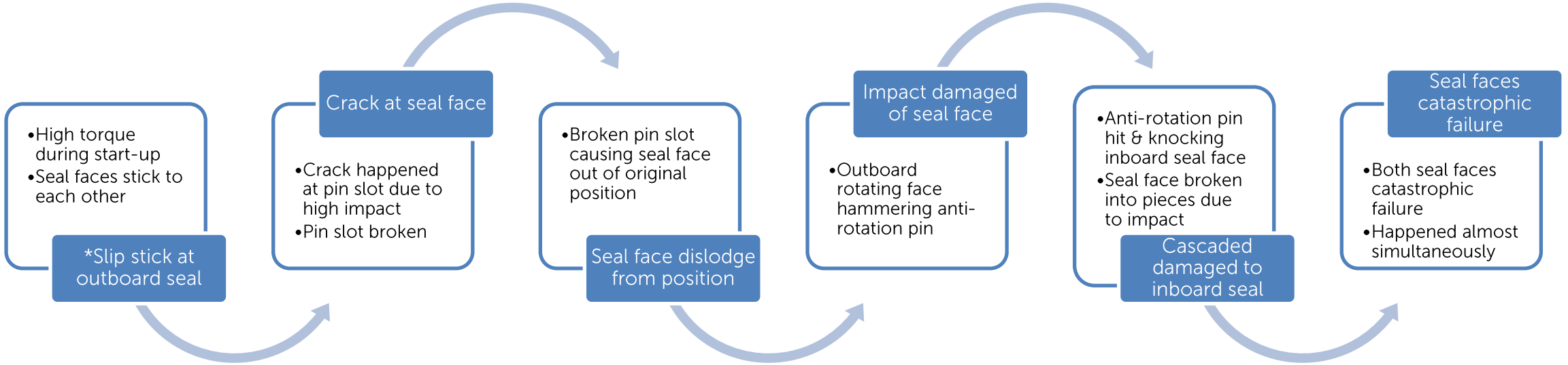
Pin shear off at outboard

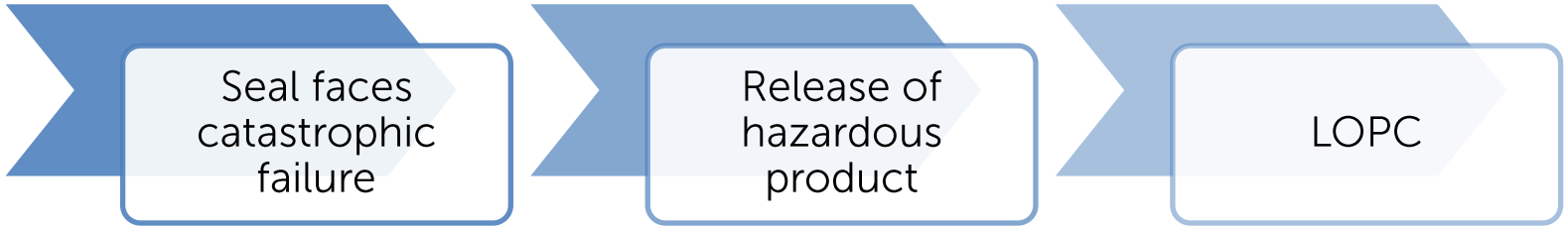
Possible Causes Elimination Process

Follow step on elimination process as per case#1 possible root causes. Some of verification task summarize as per below:

Cause Level 1	Sub Cause Level 2	Sub Cause Level 3	Sub Cause Level 4	Findings
Excessive vibration	Exposure from surrounding equipment / motor	Reaching harmonic frequency of the breaking point of seal face	Cracked or hitting other parts of mechanical seal	Installation as per procedure and meet specification 5-point check meet specification No sign of excessive vibration during start-up
Excessive shaft run-out	Shaft deflected causing seal face not perpendicular to the shaft axis	Seal face has high load concentration on edge of face : causing nose worn out	N/A	Seal face showed no sign of nose worn out 5-point check meet specification
High torque	Pin slot need to bear forces exerted during initial startup	Higher forces contributed due to “slip stick” at seal faces	Uneven friction between seal faces create huge resistance to rotate. Present of moisture at seal faces one of possible causes	Evidence of seal faces crack at / near pin slot Seal face out of position Spare mechanical seal used is taken from storage that reside for more than 2 years

Case#2: Failure Mechanism Summary



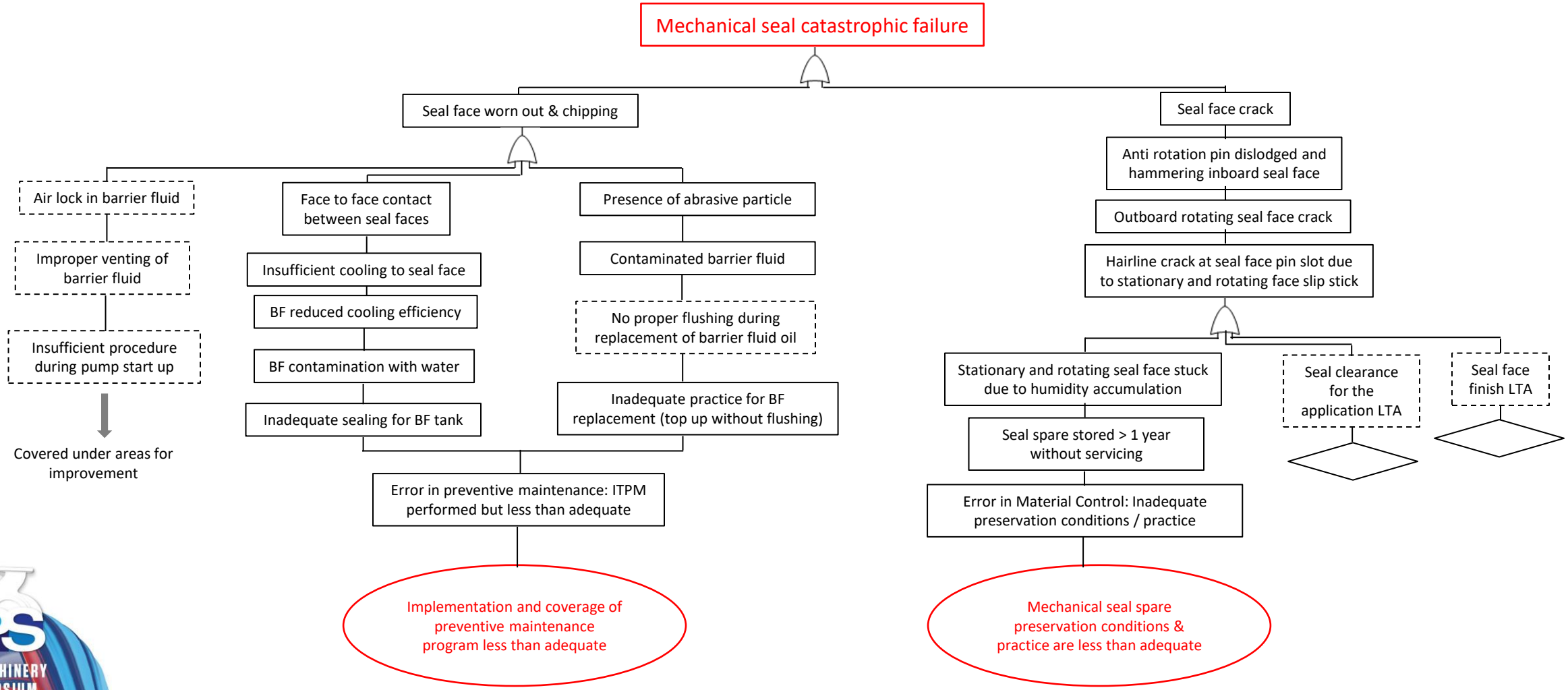


Note: Stick-slip is a common phenomenon that can occur in seals due to uneven friction between objects sliding across each other.

Fault Tree Analysis

The investigation team identified 2 root causes from confirmed events:

- Implementation and coverage of preventive maintenance program for CTP is less-than-adequate as evident in BF contamination
- Mechanical Seal spare preservation conditions & practices are less-than-adequate



Conclusion & Recommendation for case#1

Root Cause

Implementation and coverage of preventive maintenance program for CTP is less-than-adequate (BF contamination with water/sludge)

No	Recommendation	Status
1	Perform full flushing of BF for CTP during major maintenance activities.	Task already included in Maintenance Plan for Pump Changeout.
2	Replaced & maintain adequate & proper BF tank cover cap.	Defective BF tank cover cap replaced and continuously inspected during operation EBC round.
3	Ensure new sealant is applied after each BF tank cleaning activity.	The task already included in Maintenance Plan for BF tank cleaning.
4	To enhance PM task with BF system component inspection and BF flushing (6M): • Open and inspect BF condition at the BF tank • Drain and flush BF reservoir (replace 1 drum of BF). Ensure proper flushing of BF tank • Establish SOP for BF replacement in the PM task	Included system component inspection and BF flushing in 6M activity.
5	Introduce 3M task for BF inspection and sampling: • Inspect BF tank sealant and tank cap condition and ensure no leak point present. • Collect a BF sample from tank drain for visual inspection. If contamination observed (water or sludge) to raise corrective maintenance notification for BF replacement at the earliest opportunity. • CBM to perform BF analysis	Introduced BF inspection and sampling for 3M task.
6	Check CTP data on DCS & explore to tie-in DCS CTP data to PI for online monitoring & analysis.	CTP critical parameters already tied-in to PI.

Conclusion & Recommendation for case#2

Root Cause

Mechanical seal spare preservation conditions & practices are less-than-adequate (Stationary and rotating seal face stuck due to humidity accumulation-long storage item)

No	Recommendation	Status
1	Select the newest spare for installation for CTP-A DE mechanical seal.	Installed CTP-A DE mechanical seal with the newest spare.
2	Manually exercise & adequately rotate seal face to ensure no sticking condition ahead of installation.	This step has been included in mechanical seal installation procedure.
3	Send remaining spare to contractor / OEM for servicing after some period of seal in storage.	All spare mechanical seals with more than 1 year since last test were send to contractor for revalidation. This recommended practice has been included in mechanical seal preservation and storage guideline.
4	Establish a yearly program of inspection & servicing of spare mechanical seal and establish tracking database of spare mechanical seal.	Spare mechanical seal database has been developed. Spare seals are being tracked and any seal which has passed the 1 year mark will be sent to contractor for inspection and servicing.
5	Ensure adequate storage conditions for mechanical seal (controlled "air-conditioned" environment with sealed box).	All spare mechanical seals are kept in a controlled environment as specified by OEM.

Area for Improvement

Issue	Recommendation	Status
Insufficient procedure during pump start-up	To conduct a review session on CTP start-up procedure on BF venting and seal pressurization ahead of process fluid introduction.	Start-up procedure has been revised.
	To conduct a briefing session to operation personnel on the new requirement on OP.	Briefing sessions were conducted.
Insufficient design of barrier fluid reservoir tank	Proper shield at the BF tank to protect from rainwater especially during rainy season.	Weather shield has been installed at the BF tank and avoided major exposure to rainwater.
	Review requirement for barrier fluid reservoir tank design improvement, from existing design construction limitation as per following consideration: • Reorientation of inlet BF to the tank, which not sucking direct from the bottom of the tank • Adequate sight glass for contaminants monitoring • Good shelter at BF tank	These requirements are being incorporated in future pump design using BF tank.

Results Post Recommendation Implementation

- Average MTBF for CTP on mechanical seal leak used to be 1.1 month.
- Since May 2021, average MTBF for CTP has increased to 12 months and counting. The CTP have been running in good condition without any mechanical seal leak.

Lessons Learnt

- It is important to keep BF system clean and free from water ingress for mechanical seal safe operation.
- Proper preservation of mechanical seal spare is crucial to prevent deterioration on its components and unwanted condition.
- Continuous review and enhancement of PM tasks can prevent the equipment against new failure coming from new process/operating/ambient conditions.