Production Asset Integrity and Corrosion Management: Best Practices and Innovations

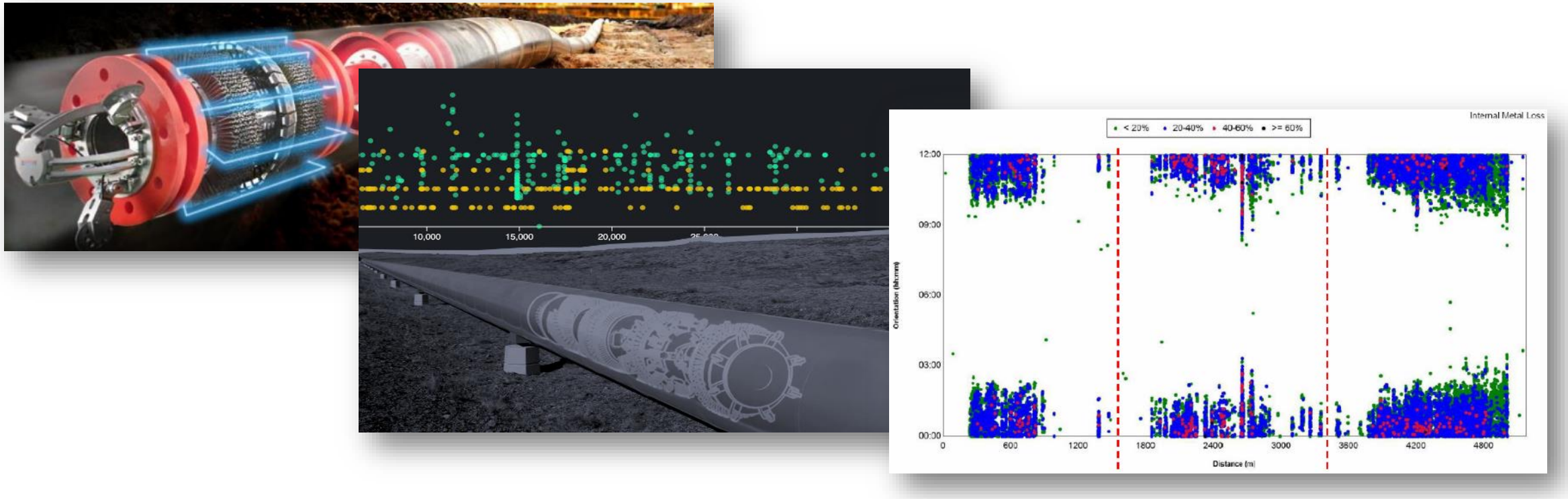
29 – 30 April 2025 | BANGKOK, THAILAND

Enhancing Effectiveness of Pipeline Integrity Management with PCMP-PL©: A Comprehensive Approach

Ahmad Fahdlam Saleh , Ir. M Zaid Kamardin & Ir. Ts. Hambali Chik
GTS, PT&HSSE, PETRONAS

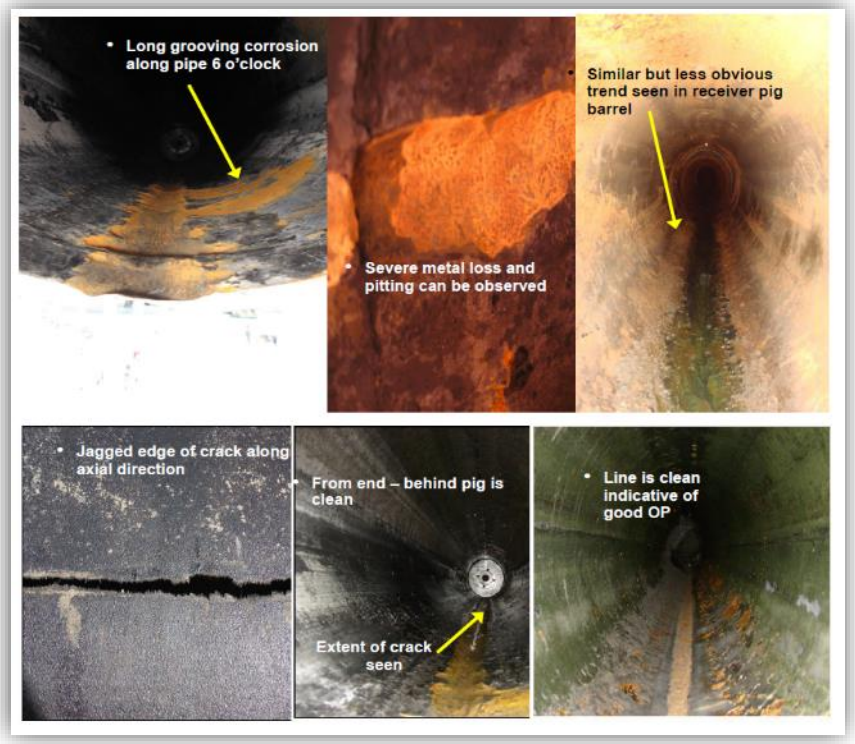
Introduction

- Pipeline integrity management primarily relies on **inspection-focused strategies**.
- While inspections provide very valuable information about the pipeline's physical condition, continuous **corrosion monitoring & control offer additional benefits** by:
  - Detecting early warning signs of potential issues beyond periodic inspections.
  - Identifying ahead of time and make proactive decisions that will positively affect the overall integrity of a pipeline.



Case for Change

Case 1



Pipeline was leak and was immediately shut down for repair. The leak causes oil spill. Cost impact including replacement, repair and revenue deferment

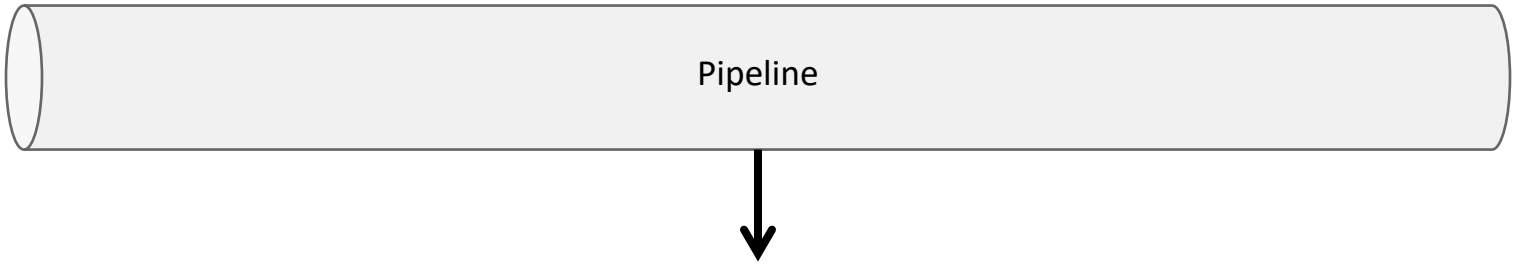
Case 2

Pipeline was found leak in due to corrosion at risers. The leak results in >5mmscf/day of gas release. Rectification activities took >5 days.

Can these Loss have been prevented with Optimum Corrosion Management Strategies and Plan?

PCMP-PL©

- PETRONAS introduced PETRONAS Corrosion Management Program for Pipelines (PCMP-PL©) to manage pipeline integrity effectively.
- PCMP-PL aim to strike a **right balance between inspect and control strategies** by focusing on high-risk damage mechanisms while reducing efforts for lower-risk threats.
- For each damage mechanisms (DM), PCMP-PL recommends the appropriate strategies including **the Integrity Operating Window (IOW)** and appropriate actions to be taken in the event of deviations from these limits.

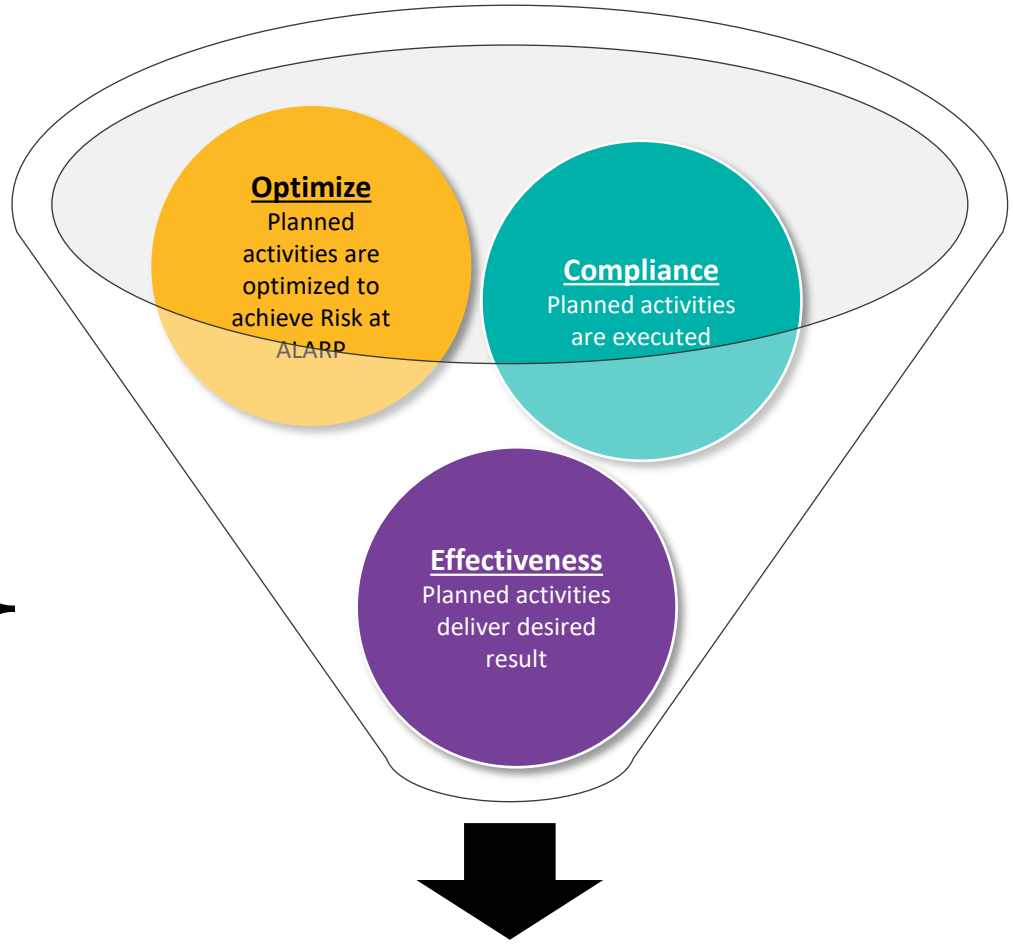


Riser External Corrosion	CO_2 Corrosion	MIC (SRB)	Erosion	External Corrosion (Subsea)
Very High	High	Low	Medium	Low
Highly extensive inspection & monitoring activities. May require other mitigation actions (repair, maintenance etc.)	Extensive inspection & monitoring	Minimal or no inspection & monitoring activities	Opportunity to optimize inspection & monitoring activities	Minimal or no inspection & monitoring activities

Achieving best-in-class CMP with PCMP-PL©

The PCMP-PL© able to ensure:

- All critical corrosion control mitigation & monitoring activities are included in CMP
- Planned monitoring activities addressed the risk factor
- Provide basis for planned/recommended CMP activities
- Consistent CMP recommendation for all involved pipeline
- Recommend monitoring limit (e.g., IOW) and action to be taken in the event of deviations from IOW.



"World-Class" Pipeline CMP

PCMP-PL© Methodology (1/4)

PCMP-PL© execution progress flow.

Pipeline In-Service Damage Mechanism

Internal Thinning
- CO_2 Corrosion
- MIC (SRB)
- Erosion
- Water injection (Oxygen corrosion & MIC)
- Under Deposit Corrosion (Scale, Wax, Sand, Debris)

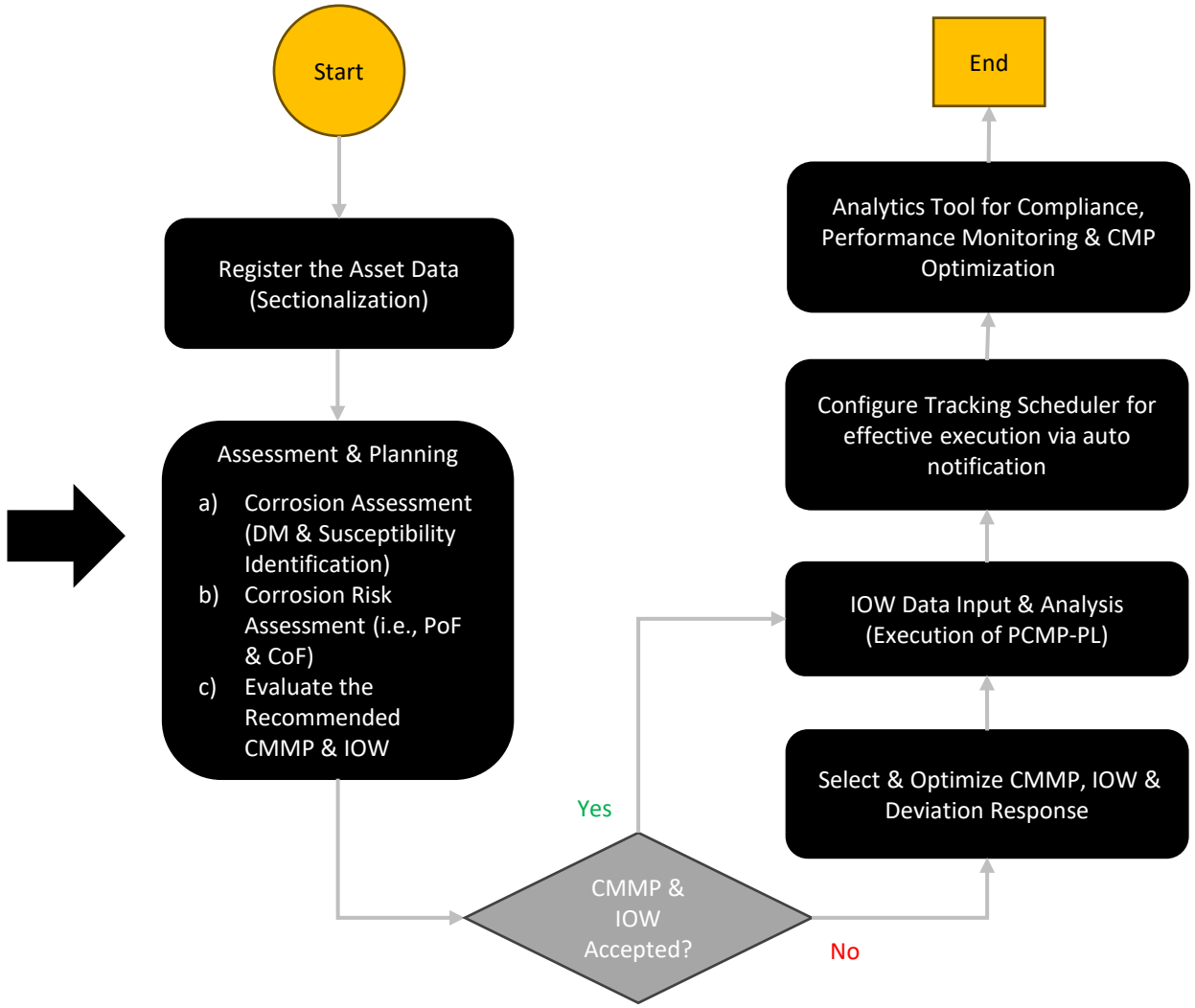
External Thinning
- Riser (Above MSL)
- Subsea (Below MSL)
- Onshore (Buried)

Environmental Cracking
- Wet H_2S Cracking

Mechanical Damage
- Dent & Gouge
- Free Span

Special Case
- Degradation of Non-metallic Material
- Flexible Pipeline
- Test Line (Intermittent Service)
- Cladded & Lined Pipeline
  - SS316L
  - Alloy 825
- Vent Pipeline
- Preserved pipelines

PCMP-PL© library covers all major damage mechanism.



PCMP-PL© Methodology (2/4)

PCMP-PL© provides clear basis for typical scenarios to identify the severity level & mitigation action

Severity/Risk	Generic and Typical Scenario	Typical Action
Very High	• Defect exceed code & standard limit • For age related DM, very short (<1 year) remaining life • For non-age related DM, damage has been detected or prolong exposure to severe condition.	• Require urgent (within 1 year) and immediate mitigation actions • Inspection and monitoring usually no longer effective to mitigate the risk
High	• Significant defect that is approaching code & standard limit • For age related DM, short (<3 years) remaining life • For non-age related DM, exposed to severe condition during normal operation	• Perform control & monitoring to reduce the risk to acceptable level (Medium or low) • More frequent Inspection and monitoring important to ensure effectiveness of corrosion control and minimal excursion to IOW. • Require detail assessment to determine best mitigation action (e.g., repair method) and time
Medium	• For age related DM, remaining life > 3 years • For non-age related DM, exposed to severe condition during upset condition	• Apply ALARP principle • Rely on inspection and monitoring.
Low	• No or insignificant defect found • For age related DM, remaining life > 10 years • For non-age related DM, not exposed to sever condition.	• Minimal inspection and monitoring is required. • Accept & Monitor

PCMP-PL© Methodology (3/4)

Recommended Corrosion Control & Monitoring Activities & Frequency

Recommended Integrity Operating Windows (IOW) & Deviation Response

Internal Corrosion – MIC

CMP Activities	Severity				Remarks
	Very High	High	Medium	Low	
Biocide Injection Compliance	100%			Not applicable	Injected together with OP
Biocide Soaking	Every 3 Months		Every 6 Months	Not applicable	Pipeline without OP and chemical skid facilities
Operational Pigging (OP) Compliance	Minimum Every 1 Week	Minimum Every 2 weeks	Minimum Every 1 month	Not applicable OP shall be based on bacteria count (water sampling)	Higher frequency may be needed based on bacteria count (water sampling and/or OP debris testing) As per PTS 11.35.04 and PTS 11.3501 requirement
Bacteria Count • Water Sampling	Every 1 month		Every 3 months	Not applicable	
Bacteria Count • OP Debris	After every OP			Not applicable	
Delta H_2S • Inlet • Outlet	Every 1 month		Every 3 months	Not applicable	
Optional CMP Activities					
Velocity Monitoring	Every 1 month		Every 3 months	Every 1 year	
Volatile Fatty Acid (VFA)	Mitigate	Every 1 month	Every 3 months	Every 1 year	
Bioprobe	Mitigate	Every 1 months	Every 3 months	Not Applicable	

Internal Corrosion – MIC (1/2)

CMP Activities	AIL			Deviation Response	
	Target	Warning	Critical	Warning	Critical
Biocide Compliance Need Close Monitoring	Performed as per CMP	-	Not performed as per CMP	-	• Determine and mitigate reason for missing injection e.g. empty drum, pump failure etc. • Carry forward (increase frequency) OP if issue persist. • Increase bacteria count (water sampling) monitoring frequency • Carry forward OP if issue extended
OP Need Close Monitoring	Performed as per CMP	Delay < 1 week	Delay > 1 week	• Verify with Bacteria Count monitoring • Inject additional BI to compensate missed OP. Batch injection, inject BI at 500ppm for 8 hours. For continuous injection: – Low Risk – No action – Medium Risk – Increase dosage by 25% – High Risk- Increase dosage by 50% • Conduct additional bacteria count • Plan for OP as soon as possible (within 3 months)	• Inject additional BI to compensate missed OP • Increase bacteria count monitoring frequency and conduct additional bacteria count • Plan for OP as soon as possible (within 1 months)
Bacteria Count – Water Sampling Need Close Monitoring	Before OP: < 10^3 CFU During OP: <10^1	Before OP: >10^3 CFU During OP: >10^1 CFU	Before OP: > 10^5 CFU	• Verify BI injection • If issue persist, increase OP frequency	• Adjust BI injection • Verify with time-to-kill test result • Increase OP frequency
Bacteria Count – OP Debris Need Close Monitoring	< 0.5kg/km for crude line < 0.25kg/km for gas line < 10^4 CFU	> 0.5kg/km for crude line > 0.25kg/km for gas line > 10^4 CFU	-	• Redo OP until cleanliness target is achieve • For future OP, increase OP frequency until bacteria count target is achieved.	-
Delta H_2S • Inlet • Outlet	<10ppm	>10ppm	-	• Verify with BI Injection • Increase monitoring frequency • Verify with other monitoring parameter	-

PCMP-PL© Methodology (4/4)

PETRONAS

PIPELINE CORROSION MANAGEMENT PROGRAM (CMP)
NFZ001

Pipeline RBI Risk (2023): **High**

A. PIPELINE DESIGN DATA

Pipeline Category	Offshore	Operator		Design Code		ASME B 31.8
Region	Central	Pipeline Service	Export Loading Line	Press. (bar)	Design	1.00
From	OFF001	Pipeline Status	Active		MAOP	2.00
To	OFF002	Design Life	12		Operating	3.00
Length	12.00	Year Commissioned	1920	Temp. (°C)	Design	12
Diameter	23	Materials of Construction	12		Operating	13

B.PIPELINE HISTORY

Risk Assessment	Final Risk	Risk Rating	Governing Threat
	B5	High	3rd Party Damage Onshore
Modification & Alteration	• N/A		
Inspection & Monitoring	• FFS completed: No anomalies challenge MAOP in inspection 2020 up to 2026. Girth weld and dent anomaly are accepted and monitored response. (PIR June 2021)		
Failure & Repair History	• Verification dig up for 1 dent defect at KP 79 (near M12 station) in Aug 2021. (PIR June 2021).		
Service Change	• N/A		

C. OPERATIONAL DATA

CO_2 Concentration (mol%)	12.00	Water Content (ppmv)	17.00	HAC Concentration (ppmV)	14.00
H_2S Concentration (ppmV)	16.00	Dew Point Temp. (°C)	111.00	O_2 Concentration (ppmV)	19.00
Bacteria Count (CFU)	13.00	Sand Production (kg/day)	18.00	Hg Concentration (ug/m^3)	15.00

D. PIGGABILITY

Piggable	Yes
Pig Type	BiDi Pig
Launcher	LTN_001
Receiver	RTN_001

E. INTEGRITY CHEMICAL

Chemical	Inj. Mode	Inj. Point	Dosage	Avai. (%)
Biocide Inhibitor	As and when required	IP_001	12	110

F. CORROSION MONITORING

Type	Location
Corrosion Probe	KUL

G. CORROSION CONTROL

PL Section		MOC	OD (mm)	WT (mm)	Coating	CP
OFF002	Riser Below Water	12 Sour	12	12	12	SACP

H. CONSEQUENCES OF FAILURE (COF)

People	Environment	Asset	Reputation	Combined
2	2	3	5	5

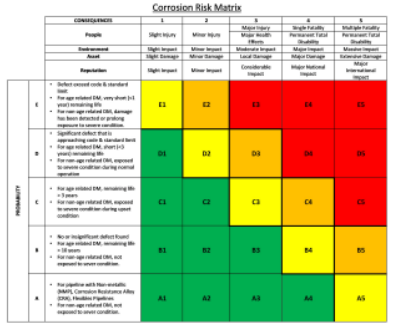
I. CORROSION ASSESSMENT

DM Category	DM	Description	Susceptibility	Corrosion Rate
External	Galvanic Corrosion	• TEST	Active	0.00
	Atmospheric Corrosion	• TEST	Active	0.00
	Stray Current Corrosion	• TEST	Not Susceptible	0.00

J. CORROSION RISK ASSESSMENT

DM Category	PL Section	DM	PoF	CoF	Corrosion Risk	Remarks
External	Riser Below Water	Atmospheric Corrosion	C	5	Very High	• test

Corrosion Risk Matrix



K. CORROSION MONITORING AND MITIGATION PLAN (CMMP)

DM	Corrosion Risk	Monitoring Parameter	Monitoring Activities	Monitoring Location	Monitoring Frequency	Responsible Party
Brittle Fracture	High	OP Compliance	Operational Pigging		Weekly	Process Engineer
Corrosion Under Insulation - Carbon Steel	Low	Corrosion Probe	Corrosion Rate Monitoring		Daily	MCI Head
Corrosion Under Insulation - CRA	Low	OP Debris	Operational Pigging		Quarterly	Reliability Engineer
Atmospheric Corrosion	Very High	Acetate	Chemical Injection		Fortnightly	Inspection Technician

L. IOW & Deviation Response

DM	Monitoring Parameter	Parameter Criticality	IOW-Lower Limit			IOW-Upper Limit			Deviation Response	
			C	W	T	T	w	C	Warning	Critical
Brittle Fracture	OP Compliance	NCM (Need Close Monitoring)	<=3.00	<=5.00	>5.00				N/A	N/A
Corrosion Under Insulation - Carbon Steel	Corrosion Probe	NCM (Need Close Monitoring)	<=7.00	<=11.00	>11.00				N/A	N/A

Corrosion Rate Monitoring | Cathodic Protection | **Sampling Analysis** | Operational Data | Operational Pigging | Chemical Injection

Tag ID: Fluid FU1 EDH Tag ID:

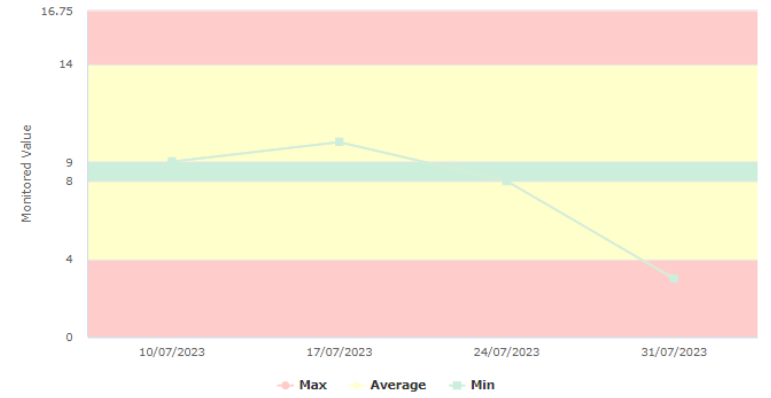
Parameter: pH Unit: n/a

Start Date: 13/07/2023 End Date: 01/08/2023

Period:* Weekly

Display curves: ☑ Min ☑ Avg ☑ Max

Generate Chart



Monitored Values

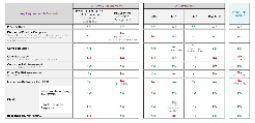
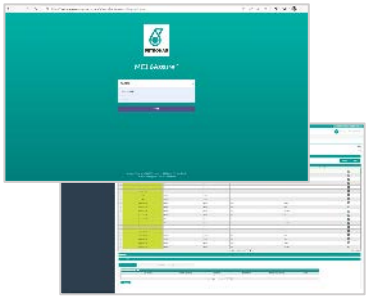
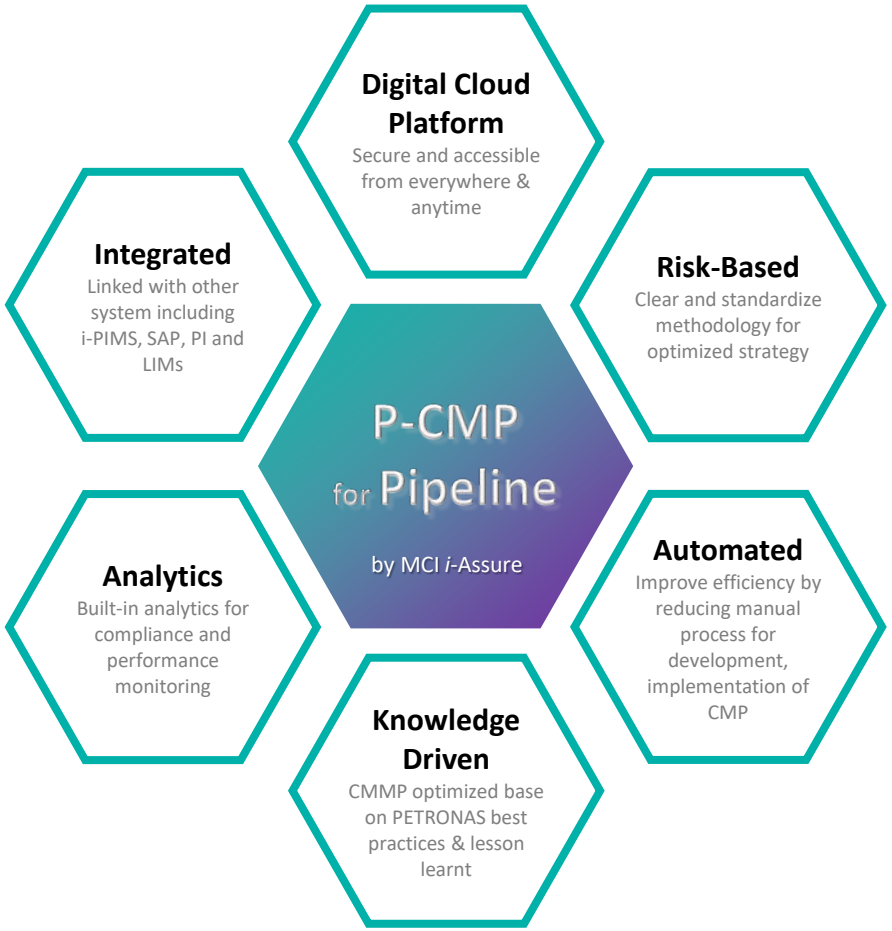
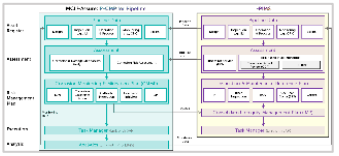
Monitored Values

Monitored Date	Monitored Value	Action
13/07/2023 11:38 AM	9.00	
20/07/2023 05:15 PM	10.00	
27/07/2023 05:22 PM	8.00	
31/07/2023 04:12 PM	3.00	

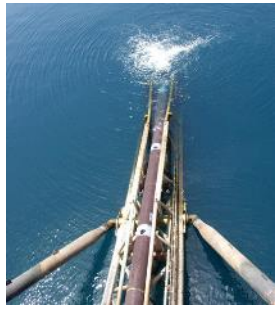
Page 1 of 1 20 View 1 - 4 of 4

Add New | Download as Excel | Upload as Excel | Download Template

PCMP-PL© Digital Solutions

	Current State	Big Idea	Desired Future State
CMP Development	**Non-Standardized & Time Consuming** • Inconsistent approach & methodology leading to non-optimized CMP  • Time consuming & requires extensive data collection, repetitive and redundant work	**Leverage digitalization to manage in-service pipeline integrity via Risk-Based Integrity Operating Window (IOW) development and implementation.**	**Standardized & Efficient** • Standardized methodology leveraging PETRONAS's experience • Optimize resources and reduce cost of CMP deployment 
CMP Implementation	**Manual & Non-Integrated Process** • High reliance on labor-intensive work process • Document & data is stored in individual/local server and not readily accessible • Execution is not or manually tracked leading to compliance issue		**Automated & Integrated Process** • Interfacing with i-PIMS, SAP, PI and LIMS to increase automation.  • Online database with cloud system accessible online, anywhere • Automatic notification and status tracking status via email
CMP Analysis and Optimization	**Inadequate Effectiveness Review & Monitoring** • IOW data and CMP KPI is not consistently analyzed & tracked • Data is not leveraged to optimize future monitoring plan		**Performance Analytics & Benchmarking** • Built-in analytics • Benchmarking of performance to encourage best practice sharing 

Case Study 1 – Loss of Opportunity for Proactive Prevention



Corrosion Inhibitor (CI) is injected but availability, dosage and performance is not consistently monitored and analysed

Construction | **Year 0** Commissioning | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** | **Year 6** | **Year 7**

No Significant Findings

55% Metal Loss!

RCA Findings

1. CI dosage has not achieved as per intended design requirement
2. CI residual monitoring was not part of monitoring program; hence no monitoring is conducted.
3. The corrosion threat also contributed by not having the specified CI availability for the pipeline

Case Study 2 – Operational Pigging (OP) Frequency Optimization

Why we need to perform Operational Pigging (OP)?

Routine pigging of pipelines is implemented to maximize operational throughput, ensure continuous operation and remove debris or deposits (liquid or solid) that may restrict flow, induce corrosion growth or prevent the effectiveness of integrity chemical application such as Corrosion Inhibitor, Biocide or etc.

Extract of PCMP-PL Guideline on OP

Severity	Damage Mechanisms	Recommended OP Frequency
Very High	MIC	Weekly
High	MIC	Every 2 weeks
	CO_2 Corrosion	Every 3 months
Medium	MIC	Monthly
	CO_2 Corrosion	Every 6 months

Example of OP Optimization Results

No.	PL	Internal Threat Risk		RL based on ICR	Current OP Freq	New OP Freq
		Main DM	Risk			
1	PL 077	CO_2 Corr.	A3 - Low	5 years	Monthly	Every 3-Months
2	PL 259	CO_2 Corr.	A3 - Low	10 years	Monthly	Every 3-Months
3	PL 261	CO_2 Corr.	A3 - Low	40 years	Monthly	Every 3-Months
4	PL 262	CO_2 Corr.	A3 - Low	21 years	Monthly	Every 3-Months
5	PL 263	CO_2 Corr.	A3 - Low	4 years	Monthly	Every 3-Months
6	PL 336	MIC, CO_2 Corr.	A3 - Low	20 years	Monthly	Monthly
7	PL 337	CO_2 Corr.	A3 - Low	53 years	2 x Monthly	2 x Monthly
8	PL 338	CO_2 Corr.	A3 - Low	15 years	2 x Monthly	2 x Monthly
9	PL 293	MIC, CO_2 Corr.	A3 - Low	24 years	3 x Monthly	3 x Monthly
10	PL 350	CO_2 Corr.	A3 - Low	24 years	2 x Monthly	Monthly
11	PL 380	CO_2 Corr.	A3 - Low	82 years	2 x Monthly	Monthly

Summary

- Superior corrosion management program is critical to ensure integrity of asset.
- Aligned with digital transformation agenda, PCMP-PL© is currently available at online platform that automates, standardizes, and simplifies the pipeline CMP lifecycle.
- This digital transformation for CMP includes key features such as a secure and accessible in cloud platform, a risk-based approach for optimized strategies, automation to reduce manual processes, knowledge-driven optimization based on best practices, and built-in analytics for compliance and performance monitoring.