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Content

KNPC TECH is a biannual publication by KNPC's Corporate Communication Department, dedicated to showcasing Engineering Excellence. Inside, you will find high-impact technical papers and the latest technological advancements driving innovation across KNPC's operations.

First issue published in 2017

(The order of the articles is randomly arranged).

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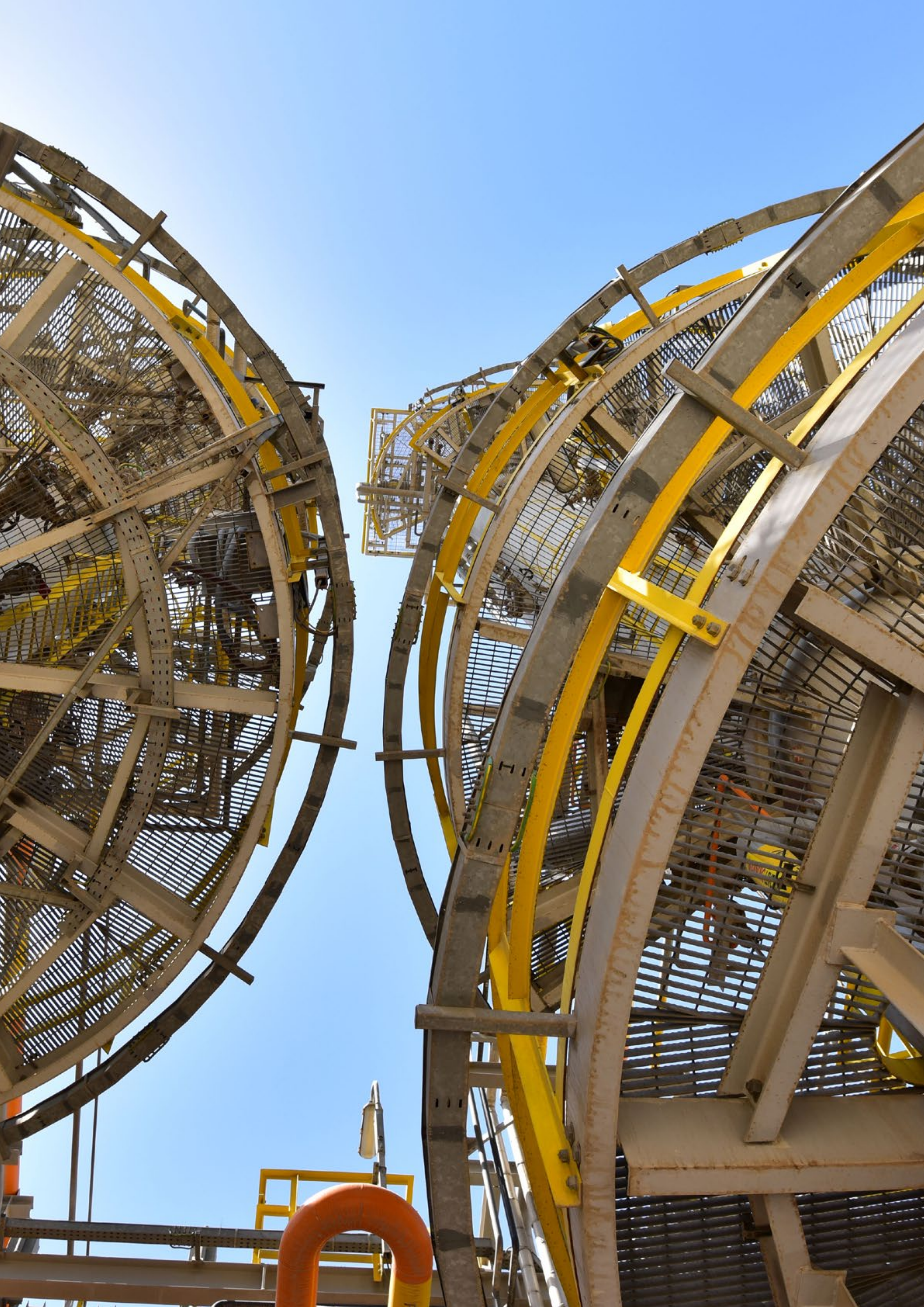

Editor's Note

In this issue of KNPC TECH, we turn the spotlight on groundbreaking technical papers presented by our own exceptional Engineers at the 22nd Kuwait/Japan Joint Symposium, held in Kuwait earlier this year. This prestigious event offered a premier platform to explore the latest advancements in refining technologies and innovations. From the symposium, we have selected five key papers that highlight KNPC's active leadership and technical contribution to the industry.

These papers vividly reflect a strategic shift toward digitalisation, machine learning, and explainable artificial intelligence (XAI), illustrating their profound impact on daily business outcomes. In the critical refining sector, efficiency, safety, competitiveness, and sustainability are no longer isolated targets. The question is no longer whether these advanced technologies should be integrated, but how swiftly we can embed them into our core operations.

We believe that the refinery of the future will not merely be defined by taller columns or larger process vessels, but by the intelligence embedded within every valve, sensor, asset, and contract. To that end, this issue explores the vital need for Digital Transformation in procurement and contract management—driving efficiency and robust governance while mitigating delays and minimising errors.

Furthermore, as refining assets grow in scale and complexity, the need for next-generation control centres becomes paramount. To operate these sophisticated systems safely and optimally, modernised facilities are critical. We take a closer look at this 'need of the hour' by detailing KNPC's commencement of the feasibility study phase for our new Central Control Rooms (CCRs).

Finally, a feature article analyses the structural and technical challenges Kuwait faces in its hydrogen transition, a vital pillar of the nation's 2060 Net-Zero Energy Strategy. This piece identifies the strategic interventions required to accelerate Green Hydrogen development in Kuwait.

We hope this issue inspires you and keeps you informed as we continue to shape the future of Energy.

Rakan Al-Fadala
Manager, Corporate Communication

Identifying Strategic Interventions to **Facilitate Green Hydrogen** Advancement in Kuwait

Green Hydrogen is increasingly recognised as a key solution for decarbonising hard-to-abate sectors. However, Kuwait's Energy System remains heavily dependent on hydrocarbons, with renewables contributing less than 2% of the national energy mix. This creates a clear gap between national climate ambitions and practical implementation.

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Introduction

While the Kuwait Hydrogen White Paper outlines high level direction, it does not provide clear operational pathways for integrating hydrogen into the national energy system.

Persistent challenges: high costs, water scarcity, and institutional fragmentation underscore the need for practical, context-specific interventions.

Accordingly, this study identifies strategic actions to advance Green Hydrogen development in Kuwait.

Research Questions Guiding the Study

The study is guided by the following major research question: What strategic interventions facilitate Green Hydrogen advancement in Kuwait? To address the same, four minor research questions were answered: (1) What barriers hinder Green Hydrogen advancement in Kuwait? (2) What interventions can address these barriers? (3) Through which mechanisms can these interventions function within Kuwait? and (4) What potential outcomes may result from integrating Green Hydrogen into the national energy mix?

Methodology

This research assumes that Green Hydrogen costs will decline over time, supported by political will and Kuwait's solar potential (Shehabi & Dally, 2021).

Using an exploratory qualitative design and the CIMO framework (Denyer et al., 2008; Kuckertz & Block, 2021), the study examined strategic interventions for Kuwait's hydrogen sector. Data were collected through semi-structured interviews with ten SMEs from key institutions including the Ministry of Oil, Ministry of Public Works, KPC, KOC, Kuwait Institute for Scientific Research, and academia. Braun and Clarke's (2006) six-phase thematic analysis was applied, with triangulation of policy documents and case studies to ensure validity (Patton & Cochran, 2002). Findings identified technically feasible and institutionally relevant interventions, prioritising qualitative insights over statistical generalisability, while ethical standards were strictly followed (Raith, 2023).

Results

The analysis triangulates evidence from a systematic literature review with insights from semi-structured interviews conducted with ten Subject Matter Experts (SMEs). Findings are organised using CIMO framework, where each CIMO component addresses a specific sub-question. Collectively, these components provide an integrated answer to the study's main research question: **Which strategic interventions facilitate the advancement of Green Hydrogen in Kuwait?**

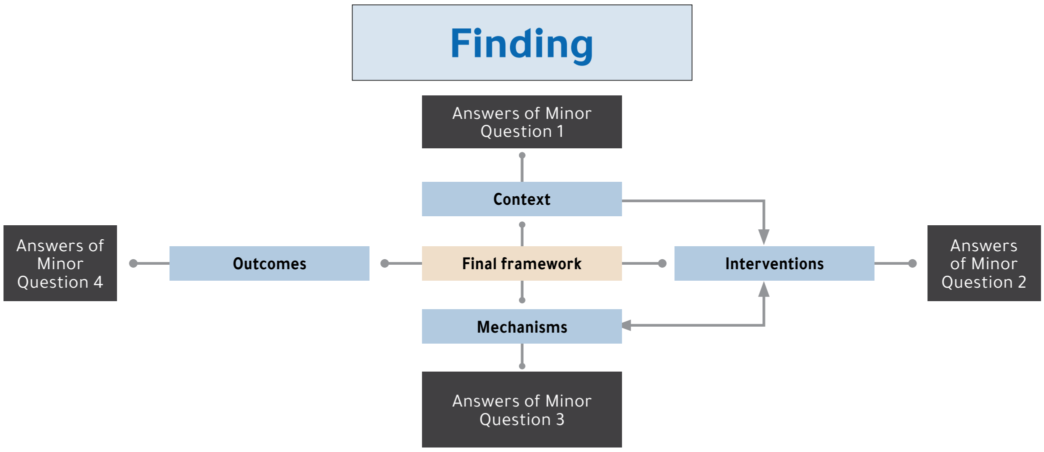


Figure 1: Conceptual Framework Linking Minor Research Questions to the Final Study Framework Source (Researcher, 2025)

1- Barriers to Green Hydrogen Advancement: Kuwait's transition is constrained by its "rentier state" structure and reliance on hydrocarbon revenues, fostering a risk-averse investment culture and limiting diversification (Alsayegh, 2021; Al-Qattan, 2025; Alaradi, 2025). High production costs using PEM technology (USD 3.22-4.41/kg by 2032) make Green Hydrogen uncompetitive without carbon pricing (Shehabi & Dally, 2021). Water scarcity and reliance on energy-intensive desalination further hinder large-scale electrolysis, requiring additional infrastructure (Shehabi & Dally, 2021; Sulaiman, 2025). Institutional fragmentation, including lack of legal frameworks, financing mechanisms, and a unified national roadmap, adds a non-technical barrier compared with other GCC states (Alsayegh, 2021; Al-Qattan, 2025).

2- Strategic Interventions: To overcome barriers, the analysis highlights leveraging blue hydrogen with Carbon Capture, Utilisation, and Storage (CCUS) to use existing hydrocarbon infrastructure and reduce capital costs (Alnori, 2025; Alaradi, 2025), while noting potential reliance on imported gas (Shehabi & Dally, 2021). Treated Sewage Effluent (TSE) offers a technical solution to water scarcity, requiring additional polishing (Al-Qattan, 2025; Sulaiman, 2025; Xylem Kuwait, 2019). Economically, developing domestic demand and employing state-backed instruments like Carbon Contracts for Difference (CCfDs), green bonds, tax incentives, and offtake agreements can lower WACC and improve project viability (KFAS, 2021; Abdulrahim, 2025; Alherz, 2025; Deloitte, 2023).

3- Enabling Mechanisms: Mechanisms are the underlying processes through which interventions are enacted and validated within the Kuwaiti state structure. For infrastructure, a pilot-based mechanism was identified as essential for de-risking projects. Stakeholders emphasised starting with small-scale pilots at sites like the Shagaya Renewable Energy Park to test feasibility and build local expertise without committing to massive immediate risks (Sulaiman, 2025). Interviewees indicated that phased scaling allows local technical capacity to mature, driving down the Levelised Cost of Hydrogen (LCOH) through economies of scale prior to full commercial rollout (Sulaiman, 2025; Shehabi & Dally, 2021).

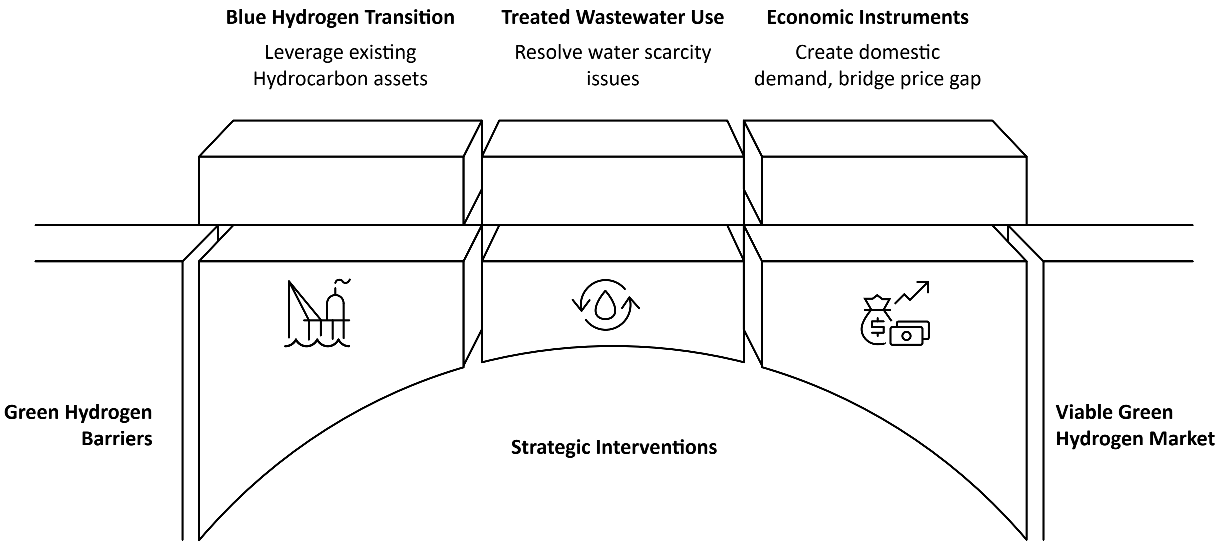


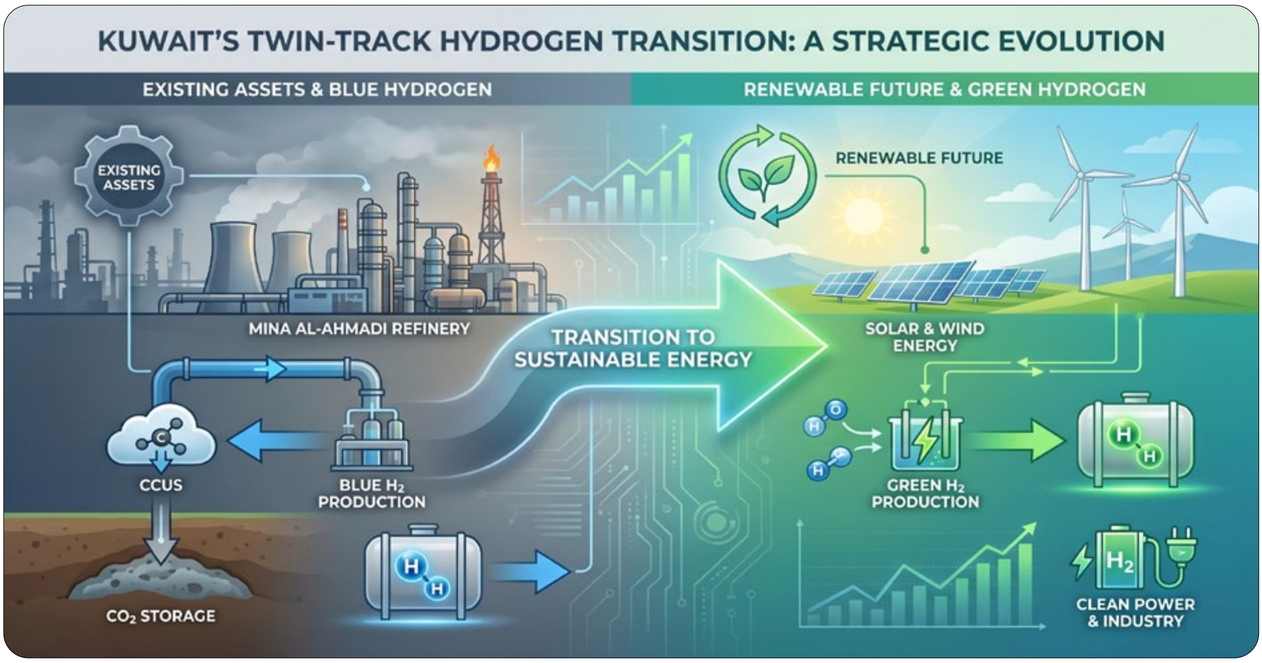
Figure 2: Intervention Pathways Supporting Kuwait's Hydrogen Transition
Source (Researcher, 2025)

4- Anticipated Outcomes: The synthesised data indicates that the interaction of these interventions and mechanisms is projected to yield economic diversification and environmental compliance. The literature estimates that while current costs are high, Kuwait's abundant solar potential could eventually lower the Levelised Cost of Hydrogen (LCOH), positioning the country as a competitive exporter to markets in Europe and Asia (Shehabi & Dally, 2021). Interviewees supported this, noting that positioning Kuwait as a regional leader in Clean Energy would hedge against the long-term decline of hydrocarbon markets and ensure compliance with international climate commitments (Al-Hajri, 2025; Al-Qattan, 2025).

The literature indicates that domestic hydrogen production utilising renewable resources would reduce the domestic consumption of oil for power generation, thereby freeing up hydrocarbon resources for export (Shehabi & Dally, 2021).

Conclusion

The analysis shows that Kuwait's hydrogen transition faces structural, not just technical, challenges rooted in its "rentier state" logic and risk-averse investment culture. Blue hydrogen can aid skill and supply chain development but should remain a transitional step due to limited natural gas imports. Water scarcity makes Treated Sewage Effluent essential for Green Hydrogen production. Centralised governance, via a Supreme Council for Green Hydrogen, is critical to coordinate efforts, enhance investor confidence, and ensure effective use of financial instruments and infrastructure retrofits.



Recommendations

1. Establish a Centralised "Supreme Council for Green Hydrogen"

It is recommended to establish a centralised governance body with statutory authority to coordinate between the Ministry of Electricity, Water and Renewable Energy (MEW) and the oil sector (KPC), align institutions, reduce administrative friction, and demonstrate long-term political commitment to attract investment.

2. Implement Financial De-Risking via (CCfDs)

CCfDs can stabilise revenues, shift carbon price risks to the government, and reduce financing costs, making Green Hydrogen projects financially viable for private investors.

3. Use Treated Wastewater (TSE)

Mandating Treated Sewage Effluent (TSE) for electrolysis ensures sustainable Green Hydrogen production without straining freshwater resources or incurring high desalination energy costs.

4. Adopt a "Twin-Track" Strategy

Using blue hydrogen as a temporary transitional step can build supply chains and technical capacity while Green Hydrogen matures, leveraging existing assets without increasing reliance on imported gas.

5. Retrofit Retired Hydrocarbon Infrastructure ("brownfield" development)

Repurposing retired oil and gas assets for hydrogen reduces costs, accelerates market entry, and leverages existing investments from the hydrocarbon era.

6. Reform Energy Subsidies with social

Safety nets can create genuine local demand for renewable energy, encourage energy efficiency, and promote cleaner technologies while avoiding public resistance.

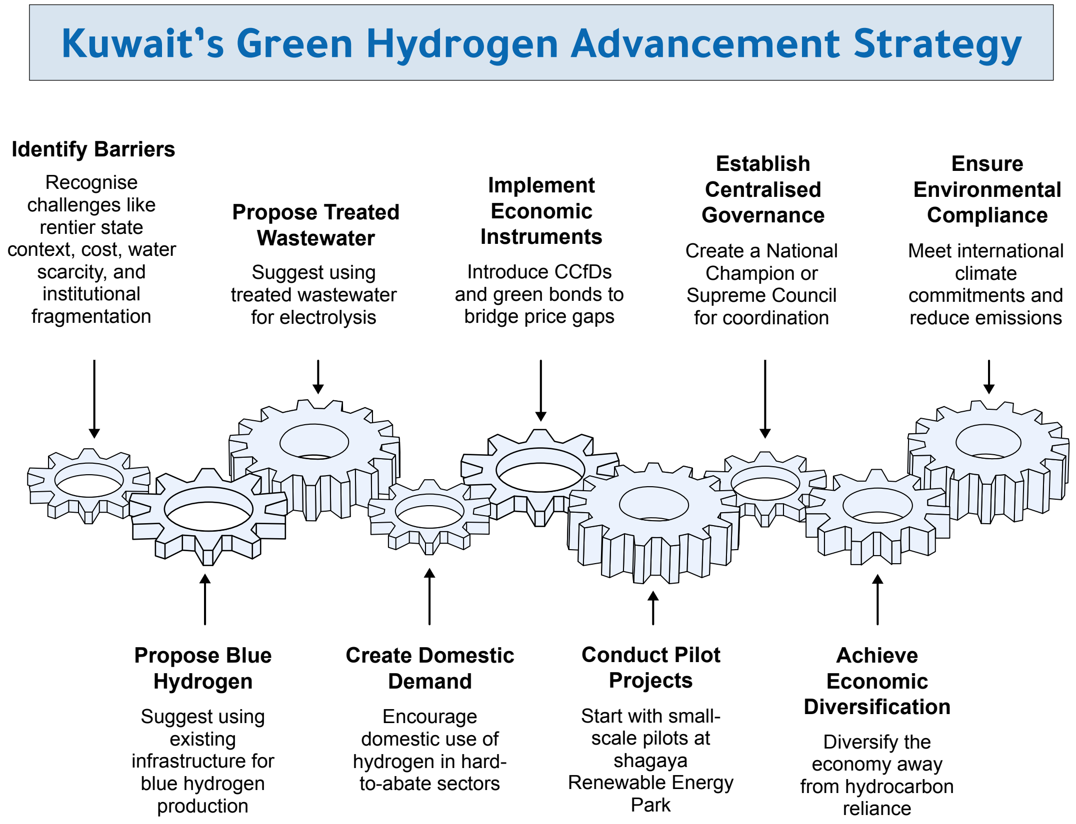


Figure 5: Roadmap for Advancing Hydrogen Production and Utilisation
Source (Researcher, 2025)

Future Research

Conduct rigorous quantitative modeling to determine the Levelised Cost of Hydrogen (LCOH) using TSE versus seawater desalination under Kuwait's specific heat and salinity conditions.

Quantify the opportunity cost of using imported natural gas for blue hydrogen versus direct electricity generation to identify the "break-even" point for transitioning to Green Hydrogen.

Develop legal frameworks to empower the proposed "Supreme Council" with authority to override conflicting ministerial mandates, addressing a common project bottleneck in Kuwait.

Acknowledgement

Sincere thanks and appreciation to the participants in this study for sharing their time and experiences:

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Engr. Fatemah Al-Momen	Ministry of Oil
Engr. Hadeel Al-Aradi	Ministry of Oil
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Dr. Ali Abdulrahim	KISR
Dr. Husam Armhan	KISR
Dr. Osamah Al-Sayegh	KISR
Engr. Jasem Al-Nori	KPC
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Dr. Mubarak Al-Hajri	PAAET

Trouble Shooting of Reaction Furnace Burner in **SRU** of **AGRP-II**

Heavy soot is observed in the acid gas burner pipe whenever the SRU is kept on hot standby condition under fuel gas firing. This soot then travels along the unit during acid gas cut in choking the downstream sulfur rundown lines and the condenser boots which lead to unit shutdown.

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Introduction

Mina Al-Ahmadi Refinery (MAA) commissioned Acid Gas Recovery Plant-II (AGRP) in Sept-2020 to process higher sour gas and sour condensate feed from KOC facilities. The AGRP II has two Sulfur Recovery Units (SRU) with 400 TPD capacity each.

From the time of commissioning, heavy soot is observed in the acid gas burner pipe whenever the SRU is kept on hot standby condition under fuel gas firing. This soot then travels along the unit during acid gas cut in choking the downstream sulfur rundown lines and the condenser boots which lead to unit shutdown. Also damage to the acid gas vanes has been observed in April'22 & Dec.'22 leading to time-consuming burner repairs. During discussion with burner vendor/licensor about the sooting problem, the lack of steam purge through the acid gas gun during fuel gas (FG) firing mode was identified to be the potential cause for burner tip damage leading to improper FG combustion.

Resolving the Sooting Problem

KNPC provided a new steam and N2 connection to the 6" acid gas line to burner which helped in resolving the sooting problem in the SRU reaction furnace burner. The paper discusses the various steps carried out to identify the root cause of sooting problem and the solution to address the same.

The unit started on fuel gas firing on 9Nov. 2021. Acid gas feed was introduced on 16 Nov. 2021, and due to gradual increase in back pressure from 0.2 kg/cm2g to 0.4 Kg/cm2g (221pi0013.pv), the acid gas was diverted back to U-220 and U-221 was taken on FG firing.

It was observed that the first S condenser E-221-004 outlet vertical boot were badly choked with hard scale material.

E-221-004 Hardened scale material found at condenser outlet boot

The II S condenser E-221-005 rundown line was also found badly choked with similar material which was cleared by rodding.

Subsequently, acid gas was introduced on 29 Nov. 2021 and cut off on 1 Dec. 2021 due to similar increase in back pressure. This time the 2nd Sulfur Condenser E- 221-005 was found badly choked. Material collected in Sultrap.

Strainer of E-221-005 is shown: E-221-0005 Sultrap strainer material 29/11/21

Loss on Heating Sulfur, Total	10.9 % mass 53.2 % mass
Carbon	0.26 % mass
Iron (Fe)	67.5 ppm wt
Silica Si Metal (Al)	0.1 ppm wt 0.2 mg/l

Soft and sooty material in rundown lines - 2.12.21

All the condenser rundown lines were de-choked and acid gas feed was re-introduced on 2 Dec. 2021 due to higher back pressure.

The material was found soft and sooty, and it was decided to remove the burner and check its condition.

Experimental

On removing the burner, the 4" tip was found completely damaged/burnt out and the 2" tip was found badly choked and cracked.

Both the 2" and 4" burner tips were replaced with new spare tips. SRU-221 lit on 17 Dec. 21. However, fuel gas firing was cut off on 18 Dec. 21 due to drop in burner tip pressure (PI0010) from 0.54 to 0.18 Kg/cm2g in visible indications of soot on view glass. On checking 2" burner with steam, it was found issuing from the 4" burner tip as well. Subsequent checks revealed a circumferential crack in the annular 2" burner pipe at approx. 18mm distance from the weld joint of the 2" burner tip and thickness loss was observed for about 200mm from the burner tip (3mm in place of 6 mm). The entire portion was replaced and burner length of 4375mm from 2" tip to end flange was ensured.

Burner lit up on 30 Dec. 21

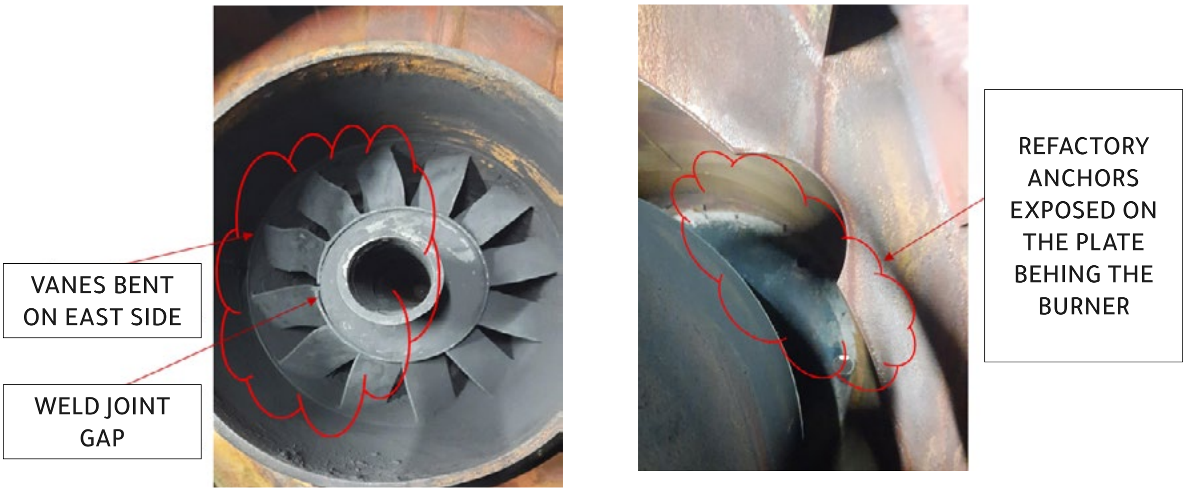
Burner was inserted and unit fuel gas firing commenced on 30 Dec. 21. Soot test was carried out at various air to fuel gas firing ratios of 12, 11, 10 & 9.5 and soot number was observed to be 1 on scale of 10.

- On 9 Jan. 22, acid gas routed to SRU-221 and due to back-pressure in SRU-221 the acid gas routed again to SRU-220 and SRU-221 become under fuel gas firing.
- On 13 Jan. 22 SRU-221 shutdown and cooled down to de-choking all condensers outlets lines.
- On 22~24 Feb. 22, de-choking of vertical boot for 221-E-003/004/0005/0008 was carried out and solid block of material blocking the mouth portion of the boot was removed. Material from E-221-004 was analysed and composition as below:

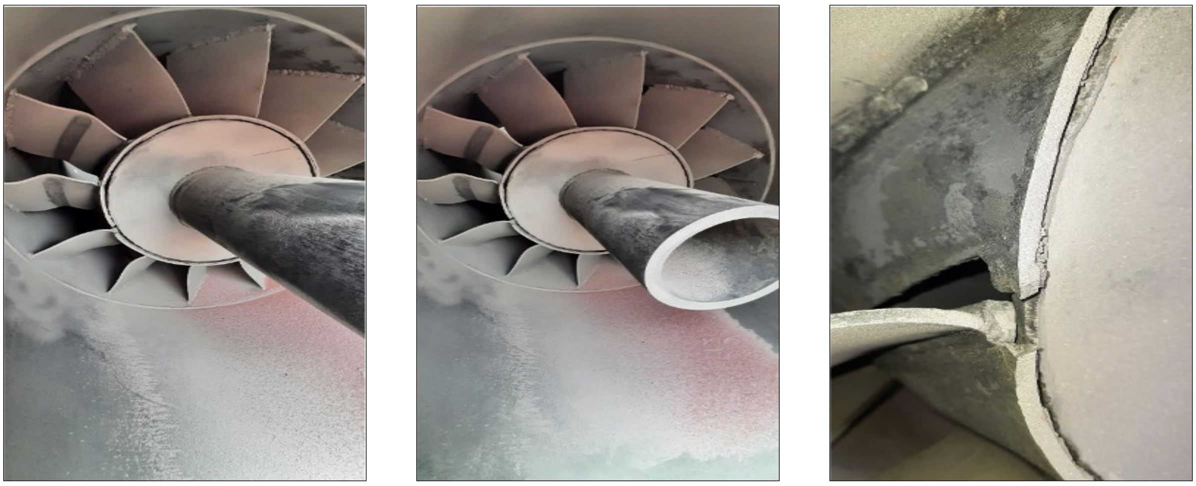
PARAMETERS	UNITS	E-221-004 CONDENSER BOOT
LOD @ 105 C°	% Wt.	2.50
LOI @ 600 C°	% Wt.	85.28
TOTAL SULPHUR	% Wt.	63.8
CARBON CONTENT	% Wt.	5.11
Fe	% Wt.	2.04
Si	% Wt.	0
Al	% Wt.	0.002

BR-221-0001 Burner Assembly - 9 Dec. 21

BR-221-001 site observation on 10 April 22 (after soot cleaning):



BR-221-001 site observation on 14 April 22 (after sweep blasting):



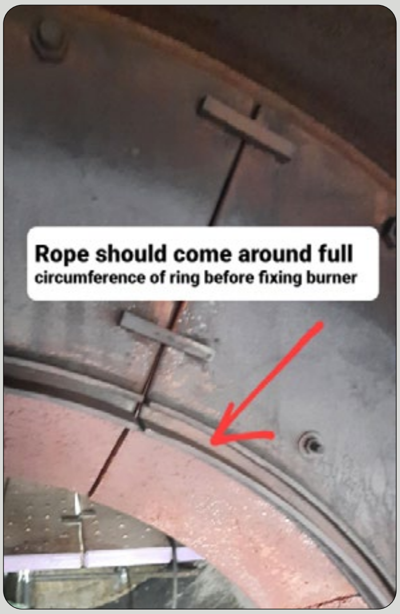
Burner and E-221-003 WHB new ferrules:

BR-221-001 Site Observation on 23 Nov. 22:

- Unit under emergency S/D from 16 Nov. 22 due to leak in E-221-008 condenser. Drop in temperature of 3rd reactor observed. While opening the inlet line to E-221-010 for blinding, water was observed coming continuously for 30 mins. Earlier burner Sooting observed earlier in soot test.
- Burner removed and checked on 23 Nov. 22. Crack observed in weld joint at the 2" weld joint to 4" tip.



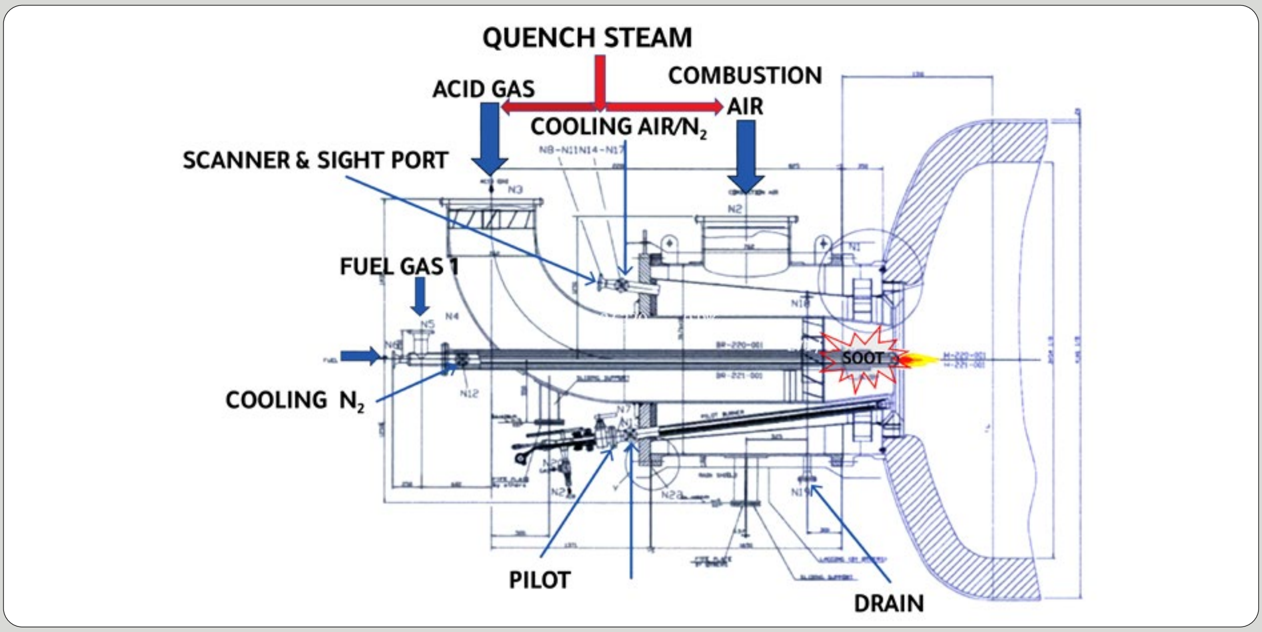

- Fissures were observed in the 4" burner tip. One refractory tile at 3'0 clock was found 50% chipped and fell down.
- Acid gas pipe was found 70-80% blocked with soot.
- 10/12 acid gas vanes were found damaged.
- TI13 A well was found broken.
- Gaps were observed in the tubesheet of WHB between hex ferrules. No sooting noticed in the tubes.
- 800/1700 tubes replaced in E-221-008 (mostly from bottom 20-40 rows).
- Vane pack mist eliminator only 2/5 Segments were good. Others found dislodged. Same was corrected at HEISCO workshop.
- E-221-010 hydrotest was done preventively.




Results and Discussion

Reasons for soot formation and action required:

- Steam addition on the acid gas side is required to avoid low-pressure mixing zones in the acid gas burner piping, which may result in improper fuel gas combustion.
- Therefore, it is proposed to provide new steam and nitrogen connections from the existing headers to the 6" acid gas line upstream of the burner.
- U-PMR-7204 implemented to provide Steam/N2 purge connections to the acid gas pipe to avoid soot accumulation and fuel gas burn back.



Conclusion

Post implementation, the burner was opened in OCT'23 shutdown and no soot accumulation was observed inside the acid gas pipe which indicates the root cause of sooting has been properly identified and resolved.

Case Study of **Gasket Upgrade** in MAB Refinery Utilising KNPC's Leak-Free Operation Guidelines

This paper will demonstrate how KNPC's approach outperformed the original equipment manufacturer design by following KNPC guideline and procedures, showcasing KNPC's technical knowledge and proficiency.

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Introduction

Gaskets are critical pressure-containing components in bolted flange joints and play a key role in maintaining leak-free operation under normal operating conditions, as well as during pressure and temperature fluctuations. Proper gasket selection is essential to ensure flange joint integrity, as gasket failures can lead to serious consequences, including hydrocarbon leakage, environmental incidents, and unplanned unit shutdowns. These failures negatively impact refinery reliability, safety, and operational efficiency.

To avoid such risks, Kuwait National Petroleum Company has established its own manual for bolting and sealing technology, titled Quality Control & Maintenance Procedure for Leak-Free Joints, and has trained several Engineers in this programme, including myself.

This paper provides a technical overview of a Gasket Upgrade in the Continuous Catalytic Reformer (CCR) unit and explains the engineering approach behind KNPC's decision to upgrade gasket types from spiral wound to kammprofile in a high-temperature operational circuit.

A case study from the Mina Abdullah Refinery (MAB) is presented, where gasket failure occurred at operating temperatures of approximately 955°F. The implemented upgrade reflects KNPC's commitment to reliability, safety, and operational excellence, demonstrating that KNPC designed gaskets outperformed those originally designed by the equipment manufacturer.

Background

The CCR unit at MAB Refinery was commissioned in August 2021 as part of the Clean Fuels Project. It is the first unit of its kind at MAB, although a similar unit exists at Mina Al-Ahmadi Refinery (MAA).

The CCR unit processes feed from the Naphtha Hydrotreater Unit (NHT) and produce high-octane gasoline (Ultra 98) along with hydrogen-rich gas and LPG. Noting that the CCR has one of the highest operating temperature units in MAB.

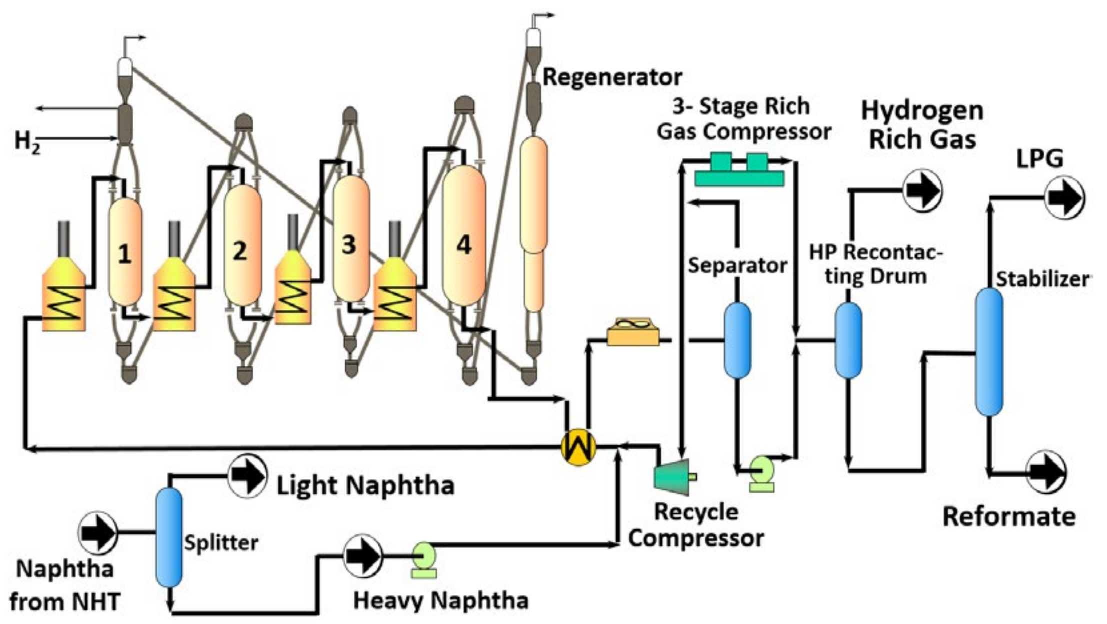

Figure 1: Process Flow Diagram

Overall Operation Conditions

- Operating Pressure: Low
- Operating Temperature: High (~1000°F)

Parameter	Value	Unit of Measurement
Feed Inlet Temp	257	°F
Top Temp	208	°F
Top Pressure	29	psig
Bottom Temp	311	°F
Packinox Exchanger, E-127-104		
Feed Inlet Temp/ Press	260 / 95.7	°F / psig
Feed Outlet Temp/ Press	793 / 75.4	°F / psig
1st Reactor, V-127-101		
Inlet Temp/ Press	955 / 71	°F / psig
Outlet Temp/Press	710.6 / 68	°F / psig
2nd Reactor, V-127-102		
Inlet Temp/ Press	955 / 63.8	°F / psig
Outlet Temp/Press	788 / 60.9	°F / psig
3rd Reactor, V-127-103		
Inlet Temp/ Press	955 / 58	°F / psig
Outlet Temp/Press	865 / 55	°F / psig
4th Reactor, V-127-104		
Inlet Temp/ Press	955 / 50.77	°F / psig
Outlet Temp/Press	880 / 47.8	°F / psig
Regenerator V-201		
1st Burning Bed Inlet	899	°F
1st Burning Bed Outlet	995	°F
2nd Burning Bed Inlet	896	°F
2nd Burning Bed Outlet	945	°F
Oxy-chlorination Inlet	950	°F
Calcination Inlet	968	°F

Figure 2: Major Operational Parameters

STAMPS method for proper gasket selection (Size, Temperature, Application, Media, Pressure, and Speed)

The STAMPS methodology is an engineering approach used for ensuring proper gasket selection by evaluating service parameters such as pressure, temperature, process media, and stress.

- **S - Size**
  Refers to flange size. Typically, MAB follows ASME B16.5 (flanges ranging from ½" to 24") and ASME B16.47. (Flanges ranging 26" to 60").

- **T - Temperature (Design Temperature)**
  The design temperature is extracted from process data provided in the design phase.

- **Application (Service Type)**
  Gasket selection depends on the type of equipment (piping, pressure vessels, pumps) and whether the service is static or rotating. Identical pressure and temperature conditions may still require different gasket types depending on the application.

- **M - Media (Process Fluid)**
  Refers to the chemical composition of the process fluid. Gasket materials must be compatible with the media to prevent corrosion, erosion or any other chemical attack.

- **P - Pressure (Design Pressure)**
  The design pressure is extracted from process data provided in the design phase.

- **S - Stress (Gasket Stress)**
  Gasket stress is the compressive stress required to achieve an effective seal. It is generated by applying the appropriate load through bolt torquing or bolt tensioning on the flanged joint. This is a key factor in achieving leak-free operation, as Maintenance Engineers cannot change the design parameters; however, they can change the gasket type based on the flange face, adjust gasket dimensions within the flange, and modify the applied torque (increase or decrease) to achieve the required gasket stress. Noting that proper control of gasket stress is essential to achieving an effective seal and preventing gasket failure.

KNPC Leak-Free Operation Procedure

KNPC established the Leak-Free Operation Procedure in February 2008 to eliminate leakage, prevent environmental incidents, and avoid emergency shutdowns. Noting that before 2008, KNPC would lose $1M ($1.52 adjusted to inflation) annually on responding to flange leaks and the consequences they produce.

- **Objectives**

The main objective of the Leak-Free Operation Procedure is to eliminate flange leakages, prevent emergency shutdowns, maintain a safe environmental atmosphere, and reduce operational costs through proper gasket selection.

KNPC's Leak-Free Operation recommends that the gaskets stress in all flanges is between 12,500 and 40,000 psi.

When gasket stress falls below 12,500 psi, leakage can occur due to insufficient clamping force on the gasket. In such cases, the flange can still be safely tightened while in service (following proper safety procedures) to increase the stress above the minimum required level, since the gasket is typically not yet damaged.

On the other hand, leakage can also occur when gasket stress exceeds 40,000 psi. This over-stressing may cause gasket crushing, where the sealing elements undergo plastic deformation and lose their ability to seal. Overtightening usually results from applying excessive loads on the bolts, which can permanently deform them making them unusable.

Also, historical data (pre-2008) showed failures due to excessive gasket stress, emphasising the importance of controlled bolt loading.

CCR Reactor Gasket Failure (May 2022)

In May 2022, a gasket failure occurred at the inlet of reactor V-127-102, resulting in an emergency shutdown.

After safe depressurisation and cooling, the gasket was replaced in-kind, meaning that the damaged gasket was replaced with a new gasket similar to the Original Equipment Manufacturer (OEM) gasket.

Then, a multidisciplinary team, in MAB, conducted a root cause analysis (RCA) and identified that the failure was associated with inadequate gasket selection for a high-temperature thermal cycling or the flange bolts were under-tightened or over-tightened.

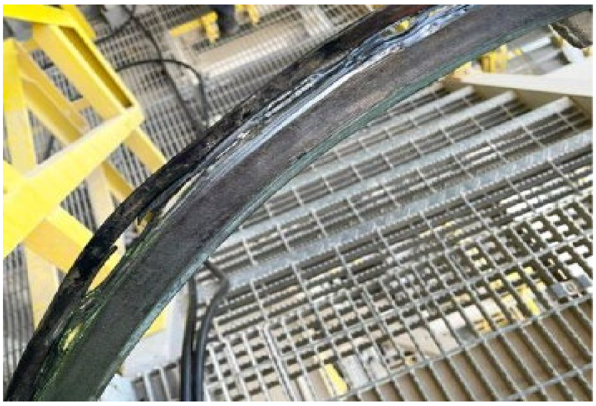

Figure 3: V-127-102 Inlet Gasket Failure (Winding Separation)

Figure 4: Winding Damage

RCA Recommendations

The RCA team concluded that the spiral wound gaskets should be upgraded to kammprofile in the reactor loop, which is a high temperature and low pressure loop, as highlighted in red below.

Noting that the replacement should occur in the nearest unit turnaround.

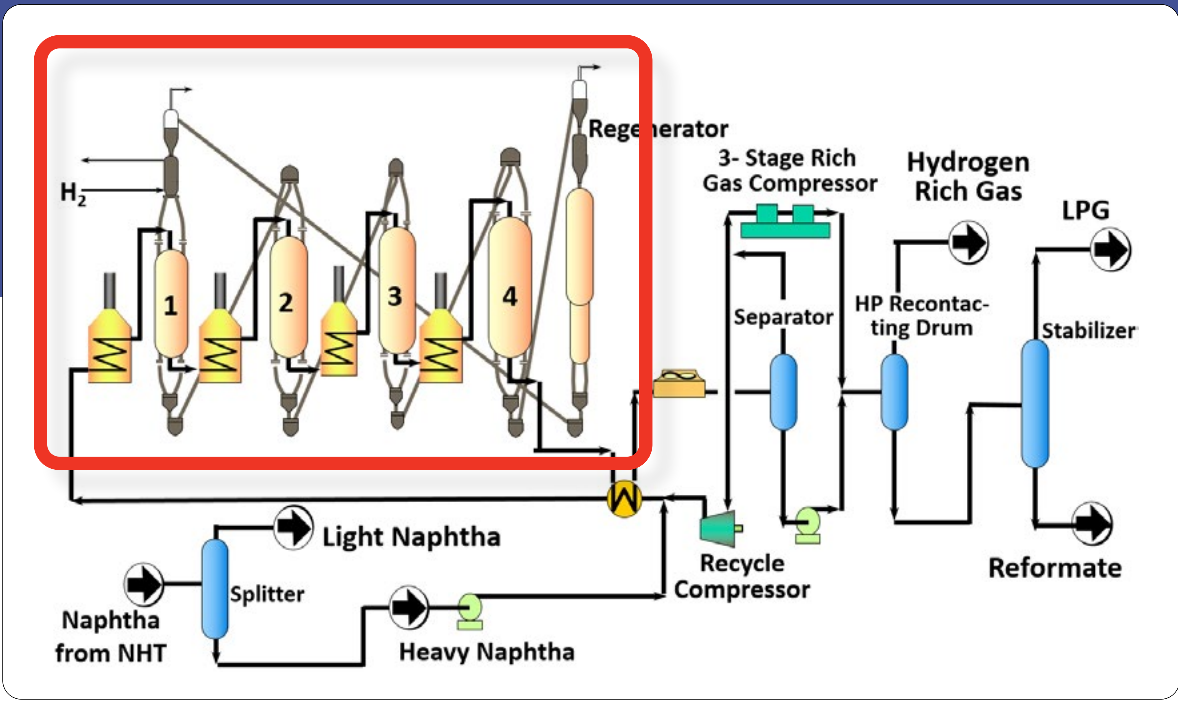

Figure 5: High Temperature Loop Where Gaskets to be Upgraded

The total number of gaskets to be upgraded in this loop was 46, and all the flanges were raised face (RF).

Quantity	Ratings	Type
4	30" x 300#	Non-Standard*
28	28"X300#	Standard
8	24" x 300#	Standard
2	28" x 150#	Standard
2	14" x 150#	Standard
2	6" x 150#	Standard

Figure 6: Gaskets to be upgraded

* The non-standard flanges have different bolts numbers of the standard, in the standard there should be 28 bolts in 30" flange, however in these special flanges there are 24 bolts.

The unit shutdown happened in March 2023 and RCA recommendations were implemented successfully.

Gasket Selection Criteria per KNPC's Leak-Free Operation

KNPC's leak-free procedure supports the upgrade of all gaskets in the reactors' circuit, based on several factors mentioned below, however the most important factor is the operation temperature, which is very high.

- **Kammprofile Gaskets- recommended for:**

- High-temperature services exceeding 950°F
- Large-diameter flanges (>24 inches)
- Applications where spiral wound gasket windings may loosen
- Critical services requiring stable sealing stress
- Vessel manways with raised face flanges.

It should be noted that all of the mentioned recommendations apply to our case.

Spiral Wound Gaskets (SW) Recommended for:

- Use Spiral Wound (SW) gaskets for raised-face piping flanges up to 950°F in Class 600, 900, and 1500.
- They may also be used for Class 150 and 300 flanges when emissions are not a concern.

Thus, it can be concluded that the RCA Teams recommendation was aligned with leak-free operation guidelines for high-temperature services and large flanges. As KNPC's leak-free procedure states, kammprofile gaskets are preferred for use in high-temperature service, large-diameter flanges, and critical applications where spiral wound gaskets may fail.

Stress and Torque Calculation

KNPC's Quality Control and Maintenance Procedure for Leak-Free Joints Manual includes calculated torque values for all standard flanges (Figure 7 & 8). In these pre-calculated tables, the gasket stress values range between 12,500 psi and 40,000 psi. This means that whenever a standard flange is used, the procedure should be referenced to determine the appropriate torque value based on the flange size and rating.

However, if there is a need to change the stress value by increasing the torque value, SME approval must be obtained, and the new bolt loads should result in gasket stress values within the range of 12,500 psi to 40,000 psi.

ASME SA-105 CS Flanges, B7 & B7M Studs
Note separate Torque Values for 300 Series SS flanges!
Slip Blind for Turnaround Isolation - No hydrotest

Mustbe Torqued | Hydraulic Torque Required | Dimensionns in Inches
Use Washers if flange is galled or badly warn.
Studs recommended for 125/150 FF Flg's. Do not mate FF Cast Iron with RF Carbon Steel.

KNPC Bolting and Torque Card Torque in Foot Pounds (FT-LB)

	150 RAISED FACE				Torque	Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's	Fp's SS
1/2	4	1/2	2 1/2	3	30	30
3/4	4	1/2	2 1/2	3	40	40
1	4	1/2	3	3 1/2	60	60
1 1/2	4	1/2	3	3 1/2	70	70
2	4	5/8	3 1/2	4	140	110
3	4	5/8	4	4 1/2	140	140
4	8	5/8	4	4 1/2	140	90
5	8	3/4	4	5	240	180
6	8	3/4	4	5	250	250
8	8	3/4	4 1/2	5	250	250
10	12	7/8	5	5 1/2	400	320
12	12	7/8	5	6	400	340
14	12	1	5 1/2	6 1/2	610	480
16	16	1	5 1/2	6 1/2	590	400
18	16	1 1/8	6	7	890	640
20	20	1 1/8	6 1/2	7 1/2	890	580
24	20	1 1/4	7	8 1/2	1,250	820

	600 RAISED FACE				Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's
1/2	4	1/2	3	3 1/2	30
3/4	4	5/8	4	4 1/2	60
1	4	5/8	4	4 1/2	80
1 1/2	4	3/4	4 1/2	5	150
2	8	5/8	4 1/2	5	80
3	8	3/4	5	6	170
4	8	7/8	6	7	360
5	8	1	6 1/2	7 1/2	530
6	12	1	7	8	480
8	12	1 1/8	8	9	770
10	16	1 1/4	8 1/2	10	890
12	20	1 1/4	9	10 1/2	940
14	20	1 3/8	9 1/2	11	1,100
16	20	1 1/2	10	12	1,450
18	20	1 5/8	11	12 1/2	2,170
20	24	1 5/8	11 1/2	13 1/2	2,030
24	24	1 7/8	13	15	2,930

	1500 RAISED FACE				Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's
1/2	4	3/4	4 1/2	5	50
3/4	4	3/4	4 1/2	5 1/2	70
1	4	7/8	5	6	120
1 1/2	4	1	5 1/2	6 1/2	280
2	8	7/8	6	7	180
3	8	1 1/8	7 1/2	8 1/2	390
4	8	1 1/4	8	9 1/2	630
5	8	1 1/2	10	11 1/2	1,010
6	12	1 3/8	10 1/2	12	820
8	12	1 5/8	12	13 1/2	1,370
10	12	1 7/8	13 1/2	15 1/2	2,150
12	16	2	15	17	2,200
14	16	2 1/4	16 1/2	18 1/2	2,590
16	16	2 1/2	18	20 1/2	4,060
18	16	2 3/4	19 1/2	22 1/2	5,760
20	16	3	21 1/2	24 1/2	7,220
24	16	3 1/2	24 1/2	28	11,520

	300 RAISED FACE				Torque	Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's	Fp's SS
1/2	4	1/2	21/2	3	30	30
3/4	4	5/8	3	4	60	60
1	4	5/8	31/2	4	80	80
1 1/2	4	3/4	4	41/2	150	150
2	8	5/8	31/2	41/2	80	80
3	8	3/4	41/2	5	160	160
4	8	3/4	41/2	51/2	240	210
5	8	3/4	5	51/2	250	250
6	12	3/4	5	6	250	210
8	12	7/8	51/2	61/2	400	340
10	16	1	61/2	71/2	490	480
12	16	11/8	7	8	760	700
14	20	11/8	71/2	81/2	670	530
16	20	11/4	8	9	980	820
18	24	11/4	8	91/2	1,060	900
20	24	11/4	81/2	91/2	1,140	900
24	24	11/2	91/2	11	1,900	1,470

	900 RAISED FACE				Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's
1/2 – 2	Not made. Use 1500 class flanges Information				
3	8	7/8	6	7	260
4	8	1 1/8	7	8	480
5	8	1 1/4	7 1/2	9	700
6	12	1 1/8	8	9	570
8	12	1 3/8	9	10 1/2	920
10	16	1 3/8	9 1/2	11	890
12	20	1 3/8	10 1/2	11 1/2	1,050
14	20	1 1/2	11	12 1/2	1,280
16	20	1 5/8	11 1/2	13	1,660
18	20	1 7/8	13	15	2,690
20	20	2	14	16	3,030
24	20	2 1/2	17 1/2	20	4,830

	2500 RAISED FACE				Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's
1/2	4	3/4	5	5 1/2	50
3/4	4	3/4	5	6	80
1	4	7/8	5 1/2	6 1/2	130
1 1/2	4	1 1/8	7	8	340
2	8	1	7	8	230
3	8	1 1/4	9	10 1/2	480
4	8	1 1/2	10 1/2	12	850
5	8	1 3/4	13 1/2	14	1,350
6	8	2	14	16	2,070
8	12	2	15 1/2	17 1/2	1,970
10	12	2 1/2	19 1/2	22	3,320
12	12	2 3/4	21 1/2	24	5,210

Note: Above 300# class the torque values for CS and SS are the same

Hvy Hex Nuts	Wrench Size
1/2	7/8
5/8	1-1/16
3/4	1-1/4
7/8	1-7/16
1	1-5/8
1-1/8	1-13/16
1-1/4	2
1-3/8	2-3/16
1-1/2	2-3/8
1-5/8	2-9/16
1-3/4	2-3/4
1-7/8	2-15/16
2	3-1/8
2-1/4	3-1/2
2-1/2	3-7/8
2-3/4	4-1/4
3	4-5/8
3-1/2	5-3/8

MAGR-MNZ3-18-1106 (5/2018)

Figure 7: Calculated Torque Values for Standard AMSE flanges ranging from 1/2" to 24"

ASME SA-105 CS Flanges, B7 & B7M Studs | Hand Tighten
Note separate Torque Values for 300 Series SS flanges!
Slip Blind for Turnaround Isolation - No hydrotest

Must be Torqued | Hydraulic Torque Required | Dimensions in Inches
Use Washers if flange is galled or badly warn.
Studs recommended for 125/150 FF Flg's. Do not mate FF Cast Iron with RF Carbon Steel.

KNPC Bolting and Torque Card Torque in Foot Pounds (FT-LB)

	150 RAISED FACE (MSS-SP44)				Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's
26	24	1 1/4	8 3/4	9 1/4	535
28	28	1 1/4	9	9 1/2	458
30	28	1 1/4	9 1/4	9 3/4	535
32	28	1 1/2	10 1/2	11	829
34	32	1 1/2	10 1/2	11	727
36	32	1 1/2	11 1/4	11 3/4	829
38	32	1 1/2	11	11 1/2	969
40	36	1 1/2	11 1/4	11 3/4	829
42	36	1 1/2	11 3/4	12 1/4	969
44	40	1 1/2	12	12 1/2	863
46	40	1 1/2	12 1/4	12 3/4	969
48	44	1 1/2	12 3/4	13 1/4	969
50	44	1 3/4	13 1/2	14	2,250
52	44	1 3/4	13 3/4	14 1/4	2,250
54	44	1 3/4	14 1/4	14 3/4	2,250
56	48	1 3/4	14 1/2	15	2,250
58	48	1 3/4	14 3/4	15 1/4	2,250
60	52	1 3/4	15	15 1/2	2,250

	400 RAISED FACE (MSS-SP44)				Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's
26	28	1 3/4	12	12 1/2	2,175
28	28	1 7/8	13	13 1/2	2,625
30	28	2	13 1/2	14	3,000
32	28	2	14	14 1/2	3,225
34	28	2	14 1/4	14 3/4	3,225
36	32	2	14 1/2	15	3,225
38	32	1 3/4	15	15 1/2	2,850
40	32	1 7/8	15 1/2	16	3,375
42	32	1 7/8	16	16 1/2	3,375
44	32	2	16 1/2	17	4,050
46	36	2	17	17 1/2	4,050
48	28	2 1/4	18 1/4	18 3/4	5,850
50	32	2 1/4	18 3/4	19 1/4	5,400
52	32	2 1/4	19	19 1/2	5,850
54	28	2 1/2	20 1/4	20 3/4	7,500
56	32	2 1/2	20 1/2	21	7,125
58	32	2 1/2	20 3/4	21 1/4	7,125
60	32	2 3/4	22	22 1/2	8,625

	900 RAISED FACE (MSS-SP44)				Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's
26	20	2 3/4	18 1/4	18 3/4	6,000
28	20	3	19	19 1/2	7,500
30	20	3	19 1/2	20	7,500
32	20	3 1/4	20 3/4	21 1/4	9,600
34	20	3 1/2	21 3/4	22 1/4	11,250
36	20	3 1/2	22 1/4	22 3/4	12,000
38	20	3 1/2	23 3/4	24 1/4	13,500
40	24	3 1/2	24 1/4	24 3/4	12,000
42	24	3 1/2	25	25 1/2	12,750
44	24	3 3/4	26 1/4	26 3/4	15,000
46	24	4	27 1/2	28	17,250
48	24	4	28 1/4	28 3/4	18,750

	300 RAISED FACE (MSS-SP44)				Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's
26	28	1 5/8	10 1/2	11	1,257
28	28	1 5/8	11	11 1/2	1,257
30	28	1 3/4	11 3/4	12 1/4	1,820
32	28	1 7/8	12 3/4	13 1/4	1,988
34	28	1 7/8	13	13 1/2	2,269
36	32	2	13 1/2	14	2,441
38	32	1 1/2	12 3/4	13 1/4	1,875
40	32	1 5/8	13 1/2	14	2,475
42	32	1 5/8	13 3/4	14 1/4	2,475
44	32	1 3/4	14 1/2	15	3,300
46	28	1 7/8	15	15 1/2	4,125
48	32	1 7/8	15 1/2	16	3,970
50	32	2	16 1/4	16 3/4	4,350
52	32	2	16 1/2	17	4,350
54	28	2 1/4	17 3/4	18 1/4	6,000
56	28	2 1/4	17 3/4	18 1/4	6,000
58	32	2 1/4	18 1/4	18 3/4	6,000
60	32	2 1/4	18 3/4	19 1/4	6,000

	600 RAISED FACE (MSS-SP44)				Torque
Pipe Size	Qty	Dia.	Length	Slip Bld	Fp's
26	28	1 7/8	14	14 1/2	2,550
28	28	2	14 1/2	15	3,000
30	28	2	14 1/2	15	3,300
32	28	2 1/4	15 1/2	16	4,125
34	28	2 1/4	15 3/4	16 1/4	4,125
36	28	2 1/2	16 1/2	17	5,250
38	28	2 1/4	18 1/4	18 3/4	4,875
40	32	2 1/4	18 3/4	19 1/4	4,875
42	28	2 1/2	20	20 1/2	6,375
44	32	2 1/2	20 1/4	20 3/4	6,375
46	32	2 1/2	20 3/4	21 1/4	6,375
48	32	2 3/4	22 1/4	22 3/4	7,500
50	28	3	23 1/4	23 3/4	9,750
52	32	3	23 3/4	24 1/4	9,750
54	32	3	24 1/4	24 3/4	9,750
56	32	3 1/4	25 1/2	26	10,875
58	32	3 1/4	25 3/4	26 1/4	10,875
60	28	3 1/2	27 1/4	27 3/4	15,000

FLANGE ASME B16.47 Series A (MSS-SP44)
Note: The torque values for CS and SS are the same

Hvy Hex Nuts	Wrench Size
1/2	7/8
5/8	1-1/16
3/4	1-1/4
7/8	1-7/16
1	1-5/8
1-1/8	1-13/16
1-1/4	2
1-3/8	2-3/16
1-1/2	2-3/8
1-5/8	2-9/16
1-3/4	2-3/4
1-7/8	2-15/16
2	3-1/8
2-1/4	3-1/2
2-1/2	3-7/8
2-3/4	4-1/4
3	4-5/8
3-1/2	5-3/8
4	6-1/8

MAGR-MNZ3-18-1106 (5/2018)

Figure 8: Calculated Torque Values for Standard AMSE flanges ranging from 26" to "60"

For the special flanges V-127-101 to V-127-104, no calculations were available, as they are non-standard. Therefore, the Leak-Free Operation Training Manual guidelines must be followed to calculate the required gasket stress and determine the corresponding torque value.

Gasket stress formula

$$G_{stress} = \frac{\mathrm{F}}{\mathrm{A}} = \frac{\text{Force of bolts} - \text{Hydraulic forces}}{Area} = \frac{A_{bolts}\, \mathrm{x} S_{stress}\ \mathrm{x}\ N_{bolts} - \left(\frac{G_{ID}}{2}\right)^2 x\ \pi\ x\ MAWP}{\pi\ x\ \left(\left(\frac{G_{OD}}{2}\right)^2 - \left(\frac{G_{ID}}{2}\right)^2\right)}$$

A_{bolts} = Area of bolts (in^2)
S_{stress} = Applied Stud Stress (psi)
N_{bolts} = Number of bolts
MAWP = Maximum Allowable Working Pressure (psi)
G_{OD} = Gasket outer diameter (in)
G_{ID} = Gasket inner diameter (in)

The gasket stress should be calculated first. As stated in the manual, the required stress values are 12,500 psi and 40,000 psi. It should be noted that the bolts used in these calculations are B16 bolts, which are designed for high-temperature and high-pressure service. The applied stud stress and the Maximum Allowable Working Pressure (MAWP) were obtained from their material specifications in accordance with ASME Section II, Part D, Subpart 1, and ASME B16.5-2003. (ASME - American Society of Mechanical Engineers).

Once the gasket stress has been determined, the corresponding torque value can be calculated using the following formula.

$$T = F\ x\ D = Force\ x\ Bolt\ Diameter = f_f\ x\ A_{bolts}\ \mathrm{x}\ S_{stress} x\ B_{dia}$$

f_f = Friction Factor
B_{dia} = Bolt Diameter (in)

Calculations for the special, non-standard 30" x 300 flanges.

$$G_{stress} = \frac{(2.3\ \mathrm{x}\ 40838\ \mathrm{x}\ 24) - \left(\left(\frac{33.2}{2}\right)^2 x\ \pi\ x\ 740\right)}{\left(\left(\frac{34.2}{2}\right)^2 \pi\right) - \left(\left(\frac{33.2}{2}\right)^2 \pi\right)} = 30{,}500\ \mathrm{psi}$$

In order to get the calculated gasket stress value the torque value should be

$$T = 0.17\ x\ 2.30\ \mathrm{x}\ 40838\ x\ 1.875 = 30{,}000\ \mathrm{lbf\ in} = 2{,}500\ \mathrm{ft{\cdot}lbf}$$

So, for this special flange the gasket stress is 30,500 psi and the needed torque value should be 2,500 ft. lbf.

Noting, that new calculations were implemented for the 28" x 300# flange. Although the Leak-Free procedure provides a torque value for this flange size, as shown in Figure 8 (since it is a standard flange), the Maintenance Team decided to increase the torque value and gasket dimensions due to high operating temperatures in this case, in order to accommodate material expansion. It should be noted that SME approval was obtained for the new calculation. The revised torque value is 1700 ft·lbf, achieving a stress value of 25,496 psi.

Conclusion

The CCR unit was commissioned in August 2021, and the original gasket failed in May 2022, indicating failure within the first year of operation. The upgraded gaskets were installed in March 2023 and have shown no failures to date. This demonstrates that KNPC's approach has been more effective than the original design provided by the original equipment manufacturer.

Since KNPC's designed kammprofile gasket outperformed the spiral wound gasket in this very high-temperature service, it can be concluded that kammprofile gaskets provide superior mechanical integrity in high-temperature applications, with reduced creep and improved sealing under fluctuating operating conditions.

Based on the data provided, it can be further concluded that KNPC's upgrade was founded on several technical approaches, including the RCA recommendations. and KNPC's Leak-Free Training Manual which both contributed to the final gasket design, ensuring that all inputs were technical and data-driven.

In conclusion, the upgraded gasket solution has significantly enhanced joint integrity and operational reliability, aligning with KNPC's strategic objectives of achieving leak-free operations, improving safety, reducing emissions, and optimising costs.

Analysis Study for the Effectiveness of Integrating Machine Learning and Explainable Artificial Intelligence into **DCS** and **IPS** in Refineries

Considering global events that directly impact oil and petroleum prices, alongside unplanned shutdowns (given the high costs and significant financial losses due to unavailability of the units), the high cost of spares, maintenance services and operational challenges are creating substantial financial impact, making proven solutions essential for sustainable relief.

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Introduction

Nowadays, most refineries around the world are using the distributed control system (DCS) and instrument protection systems (IPS) for running and monitoring. Both DCS and IPS are robust systems with limited adaptability (vulnerable to unforeseen issues) for different scenarios. For the latest years, machine learning (ML) and explainable artificial intelligence (XAI) introduced different improved-models that extend overall trust-level and accountability, focusing on accuracy and interpretability. As there are various ML methods can be used for an application, the efficiency of each method can be represented by two vital parameters which they are the Accuracy and F1 - Score. Accuracy is the overall "normal" value (the correctness) for the dataset. Basically, it is the ratio that focuses mainly on the correct prediction over the total prediction number (the correct and the false). The F1 score is the harmonic average of precision and recall, effectively balancing the model's capacity to identify all positive instances (Recall) and the dependability of its positive predictions (Precision). The two equations are demonstrated below:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

$$F1 = 2 \times \frac{TP}{TP + 0.5\ \times (FP + FN)}$$

As shown in figure 1, True Positive (TP), which means that both predictions and actual data are faulty. True Negative (TN), means that both predictions and actual data are normal. False Positive (FP), means that prediction is fault and actual is normal (false alarm). False Negative (FN), means prediction is normal and actual is fault (missed fault).

		Real Data	
		Positive	Negative
Predicted Data	Positive	True Positive (TP)	False Positive (FP)
	Negative	False Negative (FN)	True Negative (TN)

Fig. 1. The link between predicted and real data.

Methodology and Selection Criteria

This paper applies narrative literature review on recent studies published between 2023-2025 that apply different ML and XAI models in order to evaluate the effectiveness and practical feasibility of integrating ML and XAI capabilities into DCS and IPS in refineries. Additional to the general criteria, the process of choosing the studies were based on different five frameworks categories that support in assessing the selection of articles in this research. These are (A) Document Type (B) Evidence Basis, (C) Domain / Asset, (D) XAI Models, (E) Task Scope. The selection criteria were defined across five main categories: A. Document Type, where only peer-reviewed journal articles were included while pre-peer-reviewed works, theses, and industry reports were excluded; B. Evidence Basis, requiring studies to be based on experiments, simulations, or real industrial plant data, excluding purely conceptual or theoretical work; C. Domain/Asset, focusing on refinery-relevant equipment and processes (e.g., valves and heat exchangers) while excluding non-refinery applications; D. Explainable AI Models, limited to SHapley Additive exPlanations (SHAP) and Local Interpretable Model-agnostic Explanations (LIME) while all other XAI methods excluded; and E. Task Scope, targeting fault diagnosis, classification, monitoring, and early warning, while excluding Natural Language Processing (NLP), generic computer vision, and generative AI tasks.

Analytics Operationalised

The chosen papers are summarised in the Table. The results show that SHAP is being used in consistent pattern as interpretability layer on top of the system across the models that are being used in different application and task. For further clarification and to disambiguate about the role of XAI, the prediction and classification tasks is produced by the underlying machine learning algorithms such as Deep Neural Network (DNN), Support Vector Machine (SVM), and Nearest Neighbours (kNN), whereas XAI layer (the top layer) is being served as post-hoc (as interpretability layer). It provides an explanation the justification behind the produced output. That means the reviewed studies used XAI as a maps model decision, influencing the input variables, supporting overall transparency rather than being framed as predictor.

The reported results for benchmark chemical process diagnostic Continuous Stirred Tank Reactors (CSTR) and Tennessee Eastman Process (TEP) are showing a high performance across the compared algorithms with values broadly in the high-98% to ~99.9% range. From a refinery integration perspective, such near-ceiling performance, which is frequently achieved under controlled benchmark conditions, indicates that the provided underlying data quality and labeling are sufficient, contemporary machine learning models can successfully capture complex multivariate process dynamics and identify abnormal patterns. These results demonstrate the practicality of ML functions as advanced monitoring and abnormal condition recognition modules that enhance the traditional alarm management and control tactics in terms of DCS/IPS alignment. However, as the benchmark conditions usually differ from real refinery operation in disturbance structure, maintenance effects, and overall behaviour, these results should be considered as a capability indicator rather than a clear guarantee of field performance.

For more direct evidence for operational feasibility in a plant-like context, the refinery-relevant FCCU decant oil line case with a soft sensor regression performance of $R^2 = 0.93$ and a five-level risk classification accuracy of 96.42%. This combination fits with how refineries operationalise analytics, which makes it important for DCS/IPS integration. It shows how well that soft sensors can be fit into the dataset to estimate slow or delayed quality indicators in order to fill gaps in laboratory-based feedback. As the risk-tier outputs can be incorporated into operator displays, advisory alerts, and reliability workflows without replacing the underlying control layer. Overall, this case study approved that ML and XAI can be used as advisory layer integrated with historian DCS/IPS visualisation, rather than a closed-loop control replacement.

The founded results in the induction heating furnace study does not show the feasibility of integrating the machine learning and XAI only, it indicates a clear separation between higher-capability nonlinear learners and simpler baseline classifiers. Starting with the lowest accuracy, Naive Bayes models have an accuracy performance of 72.37% and a comparatively reduced F1 score of 79.73%, suggesting that conditional-independence assumptions are not well matched with the linked operational variables commonly seen in induction heating processes. In contrast, DNN achieved the strongest diagnostic performance with approximately of 91.4% for accuracy and 91.9% for F1 score. This study did not rely on predictive metrics alone, as SHAP and LIME have been used which they offer complementing post-hoc interpretability that allows for both feature-attribution insights and instance-level rationales. The practical feasibility of implementing ML and XAI based furnace diagnostics in industrial workflows, where Engineers must explain alerts and connect model outputs to physically significant drivers, is strengthened by this combination. The table demonstrates comparable high accuracy in equipment-focused diagnostics outside of process-side applications, such as a shell-and-tube heat exchanger case with 99.79% accuracy under Extreme Gradient Boosting (XGBoost) and numerous alternative models staying close to the high-accuracy domain. Additionally, rotating machinery/bearing monitoring is summarised with 98.5% for both KNN and SVM. Similarly to FCCU decant oil line case, ML and XAI integration can assist asset health functions that currently interface with DCS historians and IPS, and condition-monitoring systems without being restricted to process variables only.

The difference between early warning and problem diagnosis in the governor valve actuator scenario is a crucial finding for IPS-related viability. The resulted fault diagnosis scores are close to ceiling (about 99.64-99.93% across many models), showing strong discriminative performance. On the other hand, early-warning accuracy varies greatly, ranging from very high values of 94.286% and 99.929% where the sensor set was selected using their proposed XAI attribution workflow, to low values of 19-69% for the sensor set that was selected manually by humans.

Conclusion

The examined studies (2023-2025) indicate that integrating ML with XAI can be both effective and practically feasible for refinery-oriented applications for integrating as an augmentation to existing DCS and IPS functions. The presented findings show that high diagnostic and monitoring performance can be attained in a variety of process and equipment contexts for those are in the refinery or similar. In addition, XAI adds an interpretable layer that promotes stakeholder trust, transparency, and validation, enabled analytics in environments that are crucial for reliability and safety. A staged pilot integration of ML and XAI analytics layer with DCS/IPS historians is recommended, supported by site-specific validation and formal model governance. Both ML and XAI should be maintained alongside with human-in-the-loop decision procedures to ensure supervised use of model outputs, transparent justification of recommendations, and for smooth and safe operational adoption.

Domain / Asset	Task type	Main ML model(s) (best / focus)	XAI methods
Chemical process benchmarks (Continuous Stirred Tank Reactor "CSTR" and Tennessee Eastman process "TEP").	Fault Diagnosis	Principal Component Analysis (PCA), Autoencoders (AE), Variational Autoencoders (VAE), Adversarial Auto-Encoder (AAE)	SHAP
FCCU (the Fluid Catalytic Cracking Unit) decant oil line in a refinery.	Monitoring using Soft Sensor	Hybrid deep model: The 2D Convolutional Neural Network (2DCNN), Bidirectional Gated Recurrent Unit (BiGRU), Attention Mechanism (AM), Bidirectional Modeling	SHAP
Induction Heating furnace (similar to the transformer principle as they are based on eddy current losses principle).	Fault Diagnosis	Deep Neural Network (DNN), Extreme Gradient Boosting (XGB), Light Gradient Boosting (LGB), Random Forest (RF), Logistic Regression (LR), Multilayer Perceptron (MLP), K-Nearest Neighbour (KNN), Support Vector Machine (SVM), Decision Tree (DT), Naïve Bayes (NB)	SHAP and LIME
Rotating machinery / bearings (industrial condition monitoring).	Fault Diagnosis and Classification	Support Vector Machine (SVM) K-Nearest Neighbour (KNN)	SHAP
Shell-and-tube heat exchanger (offshore oil and gas / waste-heat power).	Fault Diagnosis	Extreme Gradient Boosting (XGB) Support Vector Machine (SVM) Convolutional Neural Network (CNN) Autoencoders (AE)	SHAP
Governor valve actuator "GVA" (Steam Turbine).	Fault Diagnosis Early Warning	Decision Tree (DT), Random Forest (RF), CatBoost, LightGBM, XGBoost	SHAP

Advancing Industrial Hygiene Monitoring: Utilisation of Innovative Technology for **VOC Detection in Refinery**

The implementation of portable GC-PID technology represents a transformative step in industrial hygiene practices, reinforcing KNPC's commitment to occupational health and safety excellence.

Mariam Awadh
Industrial Hygienist
Health, Safety and Environment Dept.

Introduction

Volatile organic compounds (VOCs) have significant occupational health risks with severe health effects including carcinogenicity. They are widely present in petroleum refinery processes. Benzene, toluene, ethylbenzene, xylenes, naphthalene, styrene, hexane, methyl tertiary-butyl ether (MTBE), 1,3-Butadiene and Cumene are just examples of common VOCs present in refineries.

Continuous advancements in industrial hygiene (IH) monitoring techniques are crucial for ensuring workplace safety and worker health in oil and gas industries.

KNPC has recently integrated the Dräger X-pid 9500, a portable gas chromatograph with photoionisation detection (GC-PID), into its armour of already highly decorated industrial hygiene equipment.

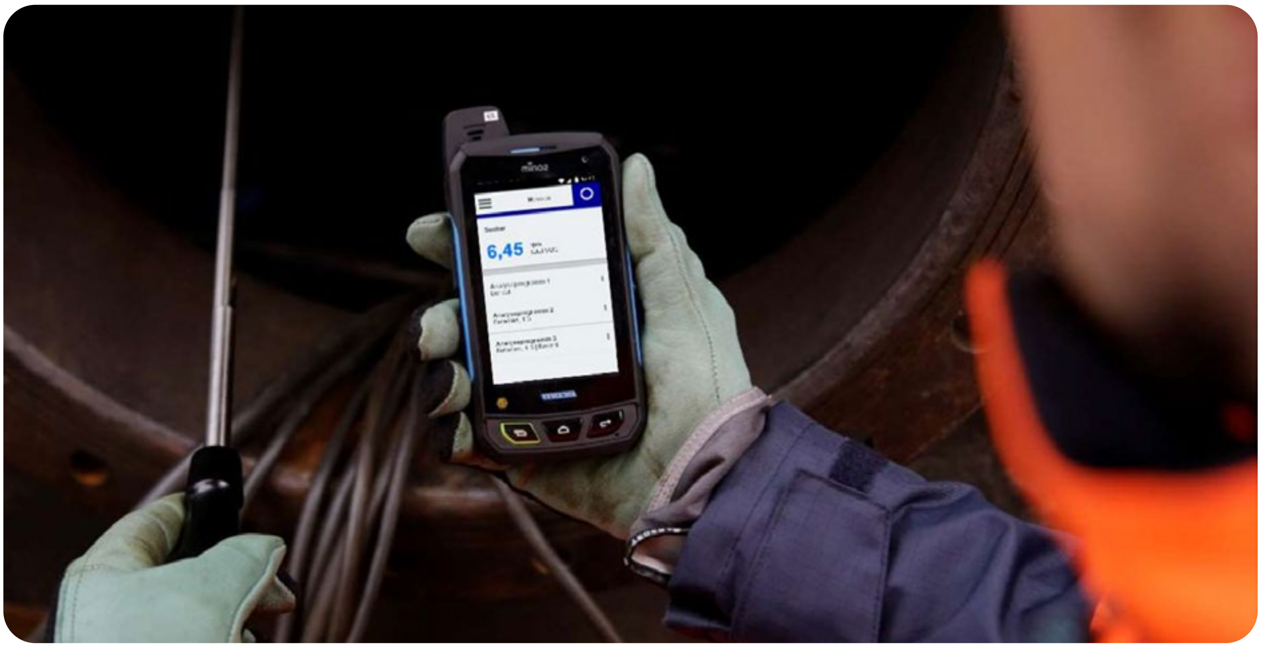
KNPC is the first organisation in Kuwait and among the few in GCC to use the X-PID-9500 in its Quantitative Exposure Assessment Programme.

This cutting-edge equipment offers rapid, selective, and highly sensitive detection of hazardous VOCs, significantly enhancing the refinery's ability to mitigate worker exposure to toxic substances.

Traditional VOC monitoring methods often rely on indirect measurement techniques or lengthy laboratory analyses, leading to delays in hazard identification and risk mitigation. The innovative GC-PID overcomes these challenges by providing real-time, on-site analysis of complex VOC mixtures, including benzene, toluene, ethylbenzene, and xylene (BTEX), as well as other known carcinogens. Its portability, selectivity, and ability to distinguish target compounds from background interferences make it an invaluable tool for industrial hygienists in refinery environments.

This paper presents case studies and field applications of the X-PID 9500 within KNPC Refineries, highlighting its role in enhancing exposure assessment and compliance monitoring. The findings demonstrate a significant improvement in risk management strategies, enabling proactive decision-making to protect worker health and ensure regulatory compliance.

The implementation of portable GC-PID technology represents a transformative step in industrial hygiene practices, reinforcing KNPC's commitment to occupational health and safety excellence. This paper will share key learnings, challenges, and recommendations for integrating advanced monitoring technologies into refinery operations, aiming to inspire industry-wide adoption of innovative solutions for VOC hazard control.



ACGIH

BENZENE

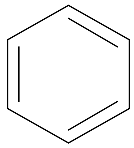
BENZENE

CAS number: 71-43-2

Synonyms: Benzol; Coal naphtha; Cyclohexatriene; Phenyl hydride

Molecular formula: C_6H_6

Structural formula:



Skin

TLV-TWA, 0.02 ppm

A1 _ Confirmed Human Carcinogen

NIOSH

(Synonyms / Trade Names) :

Benzol; Phenyl hydride

CAS NO.	RTECS NO.	DOT ID& GUIDE
71-43-2	CY1400000	1114 130

FORMULA	CONVERSION	IDLH
C_6H_6	1 ppm = 3.19 mg/m3	Ca [500 ppm] See: 71432

EXPOSURE LIMITS	MEASUREMENT METHODS
NIOSH REL Ca TWA 0.1 ppm ST 1 ppm See Appendix A OSHA PEL [1910.1028] TWA 1 ppm ST 5 ppm See Appendix E	NIOSH 1500 , 1501 , 3700 , 3800; OSHA 1005 , 500 See : NMAM or OSHA Methods

KEPA

(CAS#) 71-43-2	(Chemical Formula) C_6H_6	Benzene
(Synonyms / Trade Names) : Benzol; Phenyl hydride		

(Permissible Exposure Limits, PEL)		
ppm	mg/m³	
1.0	-	Time-Weighted Average (TWA-8 hours Shift)
5.0	-	Short-Term Exposure Limit (STEL- 15min)
500	-	Immediate Danger to Life and Health (IDLH)

(Measurement Methods)	
1500, 1501, 3700, 3800	NIOSH
12 , 1005	OSHA

NIOSH : National Institute for Occupational Safety & Health
OSHA : Occupational Safety & Health Administration
(GC/FID).

KEPA Kuwait Environment Authority

NIOSH The National Institute for Occupational Safety and Health (NIOSH)

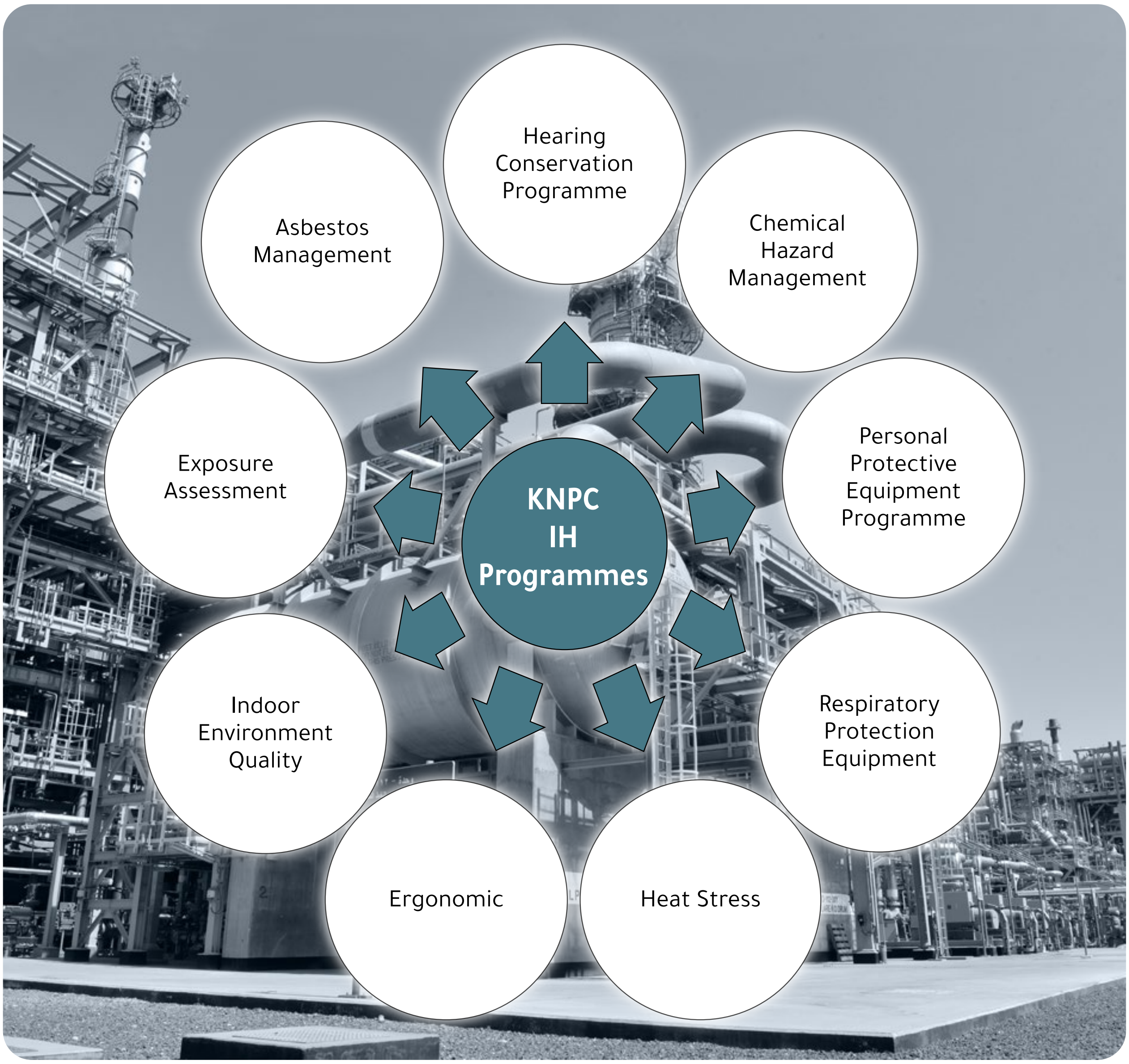
ACGIH The American Conference of Governmental Industrial Hygienists

IH Monitoring at KNPC

KNPC has 9 different programmes to minimise occupational health hazards, it is totally committed to worker health and KEPA compliance.

The quantitative exposure assessment (QEA) programme monitors 29 stressors, which involves a third-party laboratory analysis. The laboratory analysis is accurate and is required for compliance surveys, however it is time-consuming.

Therefore, KNPC has scouted for real time detection of VOCs to take immediate control measures and carried out market survey for advanced exposure monitoring technologies. The X-pid 9500 from Drager was studied and integrated into QEA.



The Drager X-Pid 9500

The Drager X-pid 9500 has the following features:

- Portable gas chromatograph with photoionisation detection (GC-PID).
- Real-time, selective measurement.
- Enhanced detection of hazardous VOCs in parts per billion (ppb).
- Improved risk management.

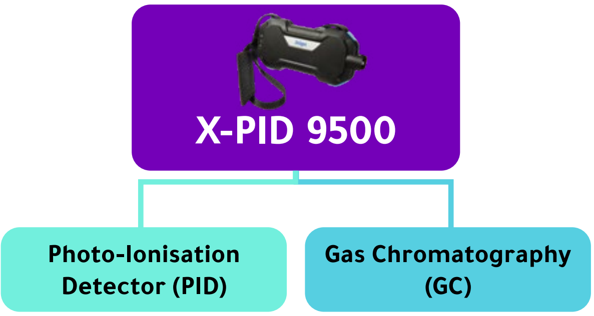
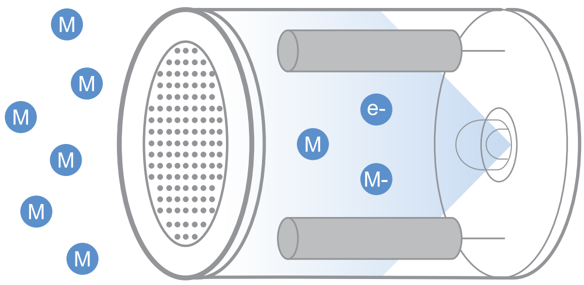


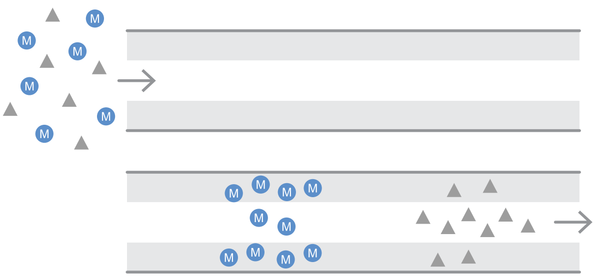
Photo-Ionisation Detector (PID)



- Molecules are ionised by UV radiation.
- Ionisation releases electrons.
- Electrons are trapped by electrodes.
- Electric current is measured and recorded.

IH Monitoring at KNPC
Gas Chromatography

- Separates different molecules in gas/ vapor mixtures.
- Different molecules take different times to pass through the GC column called retention time.
- Software identifies the molecule and concentration using retention time.



Equipment Benefits

- Selective benzene measurement within 30 seconds.
- 90%-time savings compared to conventional methods.
- Real-time results are accessible on-site with data export.
- Data export through a mobile device via emails, bluetooth, Wi-Fi from remote location.
- Detection of 18 specific VOCs simultaneously.
- Better identification of VOC sources.
- Laboratory quality measurement results.

KNPC Trials

- As the X-PID 9500 is Innovative Technology an extensive trial was carried out before employing the equipment in KNPC Industrial Hygiene Monitoring programme.
- The trials were divided into following steps.
- **Field Trials**

  The equipment was used in a real-world scenario inside refinery units to detect VOCs present in the atmosphere during normal operation. Both area monitoring and monitoring during hazardous activities like process sample collection, maintenance activities and confined space entry were carried out.

- **Performance and Accuracy Trials**

  Gasoline was selected as the chemical for which performance trials were carried out. Gasoline samples were subjected to Quality Control laboratory analysis for benzene and toluene were compared with X-PID 9500 air sample analysis for the same gasoline sample. This in turn was compared with Safety Data Sheets (SDS) of KNPC gasoline product. The trial established the performance of X-PID as accurate in the industrial setup.

- **Certifications and Productivity**

  All the documents related to the equipment certification like ATEX and cost effectiveness for employing it in the KNPC were studied and were found to be acceptable.

- **Improvements**

  Multiple meetings were held with the manufacturer M/s Dräger and KNPC suggested improvements over the current device which are being incorporated by manufacturer.

Field Applications

- Helps in identifying VOC sources in the refinery. (Equipment/ hazardous activities).
- Conducts analytical studies to detect various VOCs.
- Detects VOCs in indoor work environments such as laboratories and stores.
- Detects odour-specific VOCs for odour management.
- Contributes to key improvements in exposure assessment and emergency response.
- Supports accurate and comprehensive exposure control strategies.
- Enhances regulatory compliance.
- Enables more effective qualitative exposure risk assessments.

Benefits

- Significant impact on KNPC's industrial hygiene strategy.
- Supports a comprehensive exposure control strategy.
- Enables area monitoring for VOC source identification.
- Helps in strategising breathing zone monitoring for direct worker exposure.
- Recommends engineering controls to eliminate/ reduce potential exposure.
- Facilitates medical/biological monitoring for long-term health.
- Supports exposure assessment and PPE decision-making.
- Detects hazards beyond traditional gas monitor. (e.g, confined spaces)
- Enables proactive risk management through real-time data.

Challenges

- The need for extensive training to ensure proper utilisation.
- Potential background interferences in high-hydrocarbon environments.
- Initial costs of equipment acquisition and maintenance.
- Functional tests must be carried out every 24 hours.
- Limitation of equipment operating temperature in the Kuwaiti environment remain a challenge.

Outlook

- Integration of predictive analytic.
- Wearable devices and digital monitoring platforms.
- Connected safety solutions for zero incidents.
- Advanced training programmes.
- Improved technologies for GCC climate.
- AI- and IoT-based monitoring solutions.

Conclusion

- The implementation of GC-PID technology at KNPC represents a significant advancement in Industrial Hygiene Monitoring.
- The X-pid 9500 has demonstrated its ability to enhance exposure assessment, improve worker safety, and ensure regulatory compliance.
- The adoption of such advanced technologies will continue to play a crucial role in refining occupational health practices as industries evolve.

Smart Sustainability: Machine Learning Driven COD Prediction for **Wastewater Optimisation**

Petroleum refining generates large volumes of wastewater containing hydrocarbons and complex pollutants that must be treated before discharge. At Mina Abdullah Refinery, wastewater is treated to meet regulatory standards. However, fluctuations in influent composition and operational conditions can affect treatment performance especially for COD, ammonia, and nitrogen compounds.

Bader Jamal

Safety Engineer

Health, Safety and Environment Dept.

Introduction

Kuwait's dependence on desalinated water and its position as a major oil producer make environmental protection essential. Petroleum refining generates large volumes of wastewater containing hydrocarbons and complex pollutants that must be treated before discharge. At Mina Abdullah Refinery, wastewater is treated in the Effluent Treatment Facility (ETF) to meet regulatory standards. Operational data analysis revealed several challenges such as variability in influent wastewater quality, seasonal fluctuations affecting nitrogen removal, occasional non-compliance in ammonia and nitrate, and dependence on delayed laboratory analysis. Traditional monitoring methods rely on laboratory testing, which delays decision-making. This study introduces a data-driven approach using machine learning to enable predictive and proactive wastewater management.

The effective treatment of refinery wastewater is critical to ensure environmental compliance and sustainable operations. This study presents a machine learning-based approach to enhance monitoring and prediction of wastewater treatment performance. A Random Forest regression model was developed using historical operational data from the refinery's Effluent Treatment Facility (ETF), trained to predict effluent chemical oxygen demand (COD) based on key influent and process parameters. Results demonstrate reliable prediction accuracy, with residuals approaching near-zero values, reflecting strong learned relationships between input variables and effluent quality. Critically, as model accuracy improves through continuous alteration and feature engineering, the predictive framework can be further utilised as a real-time early detection system capable of identifying process deviations, abnormal influent loads, and potential compliance breaches before they manifest in effluent measurements. This proactive capability supports regulatory compliance with Kuwait Environment Public Authority (KEPA) standards while offering tangible opportunities for cost reduction, resource optimisation, and enhanced operational decision-making.

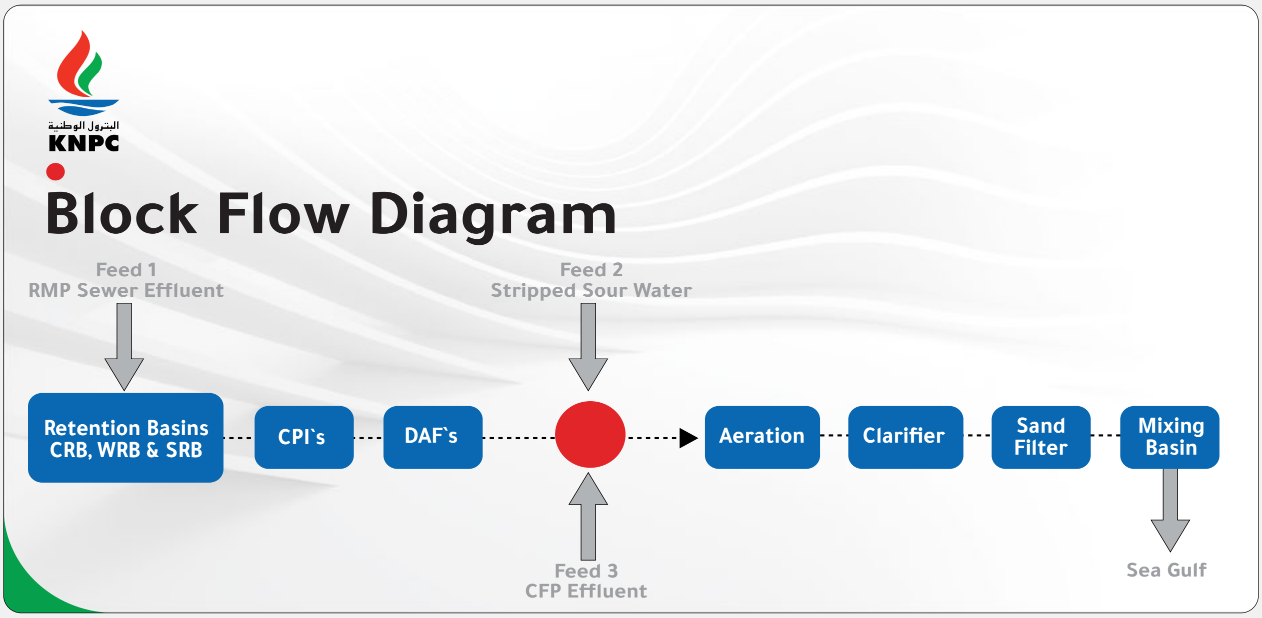


Figure (1): Block Flow Diagram of KNPC-MAB Effluent Treatment Facility

Key Findings: System Performance

Historical data from 2022-2024 was analysed, focusing on key parameters:

1. Measured parameters are pH / oil and grease / Total suspended solids (TSS) / COD / ammonia/Total Kjeldahl Nitrogen (TKN) / phenols.
2. High removal efficiency for COD, oil and highly maintained pH.
3. Stable operation under normal conditions.
4. Seasonal variability affects ammonia and nitrates especially during operational shutdowns.

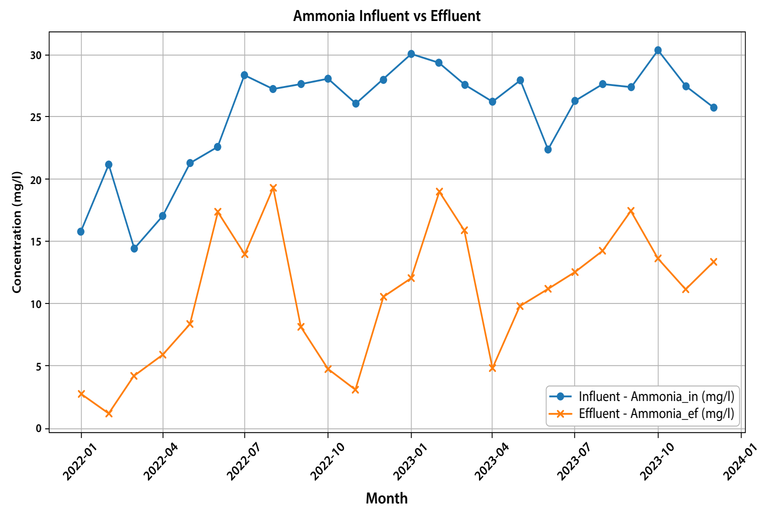


Figure 2. Effective performance of ammonia removal over two years

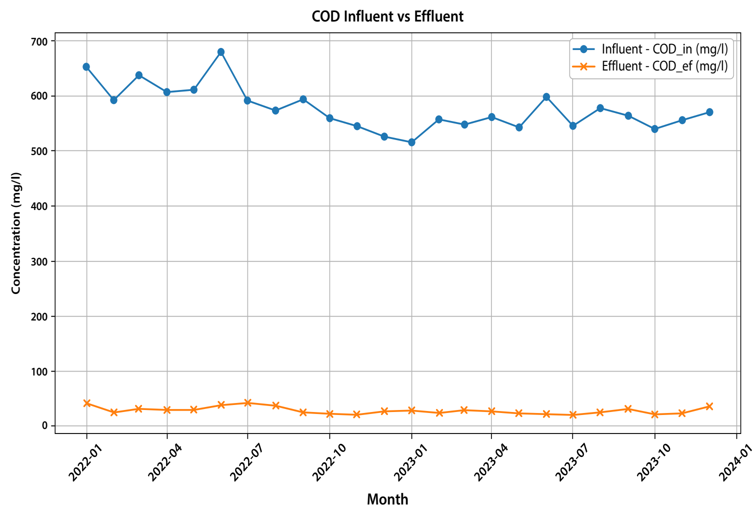


Figure 3. Changes in Chemical Oxygen Demand (COD) for Influent and Effluent Over 2 Years

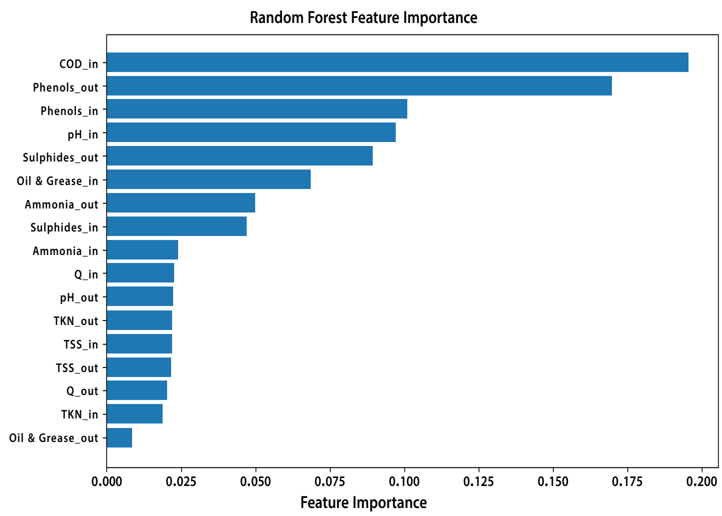


Figure 4. Random Forest Feature Importance

Model Development

A Random Forest regression model was selected due to its ability to handle complex, non-linear relationships in environmental datasets. The methodology included, data preprocessing (missing values, scaling), feature engineering, model training and validation, and performance evaluation Mean Squared Error, Mean Absolute Error, Root Mean Squared Error, and R-Squared (MSE, RMSE, MAE, R^2).

The model identified COD_in, phenols_in, and phenols_out as the most influential parameters affecting COD prediction, however since only the inputs can be controlled, COD_in and phenols_in were chosen.

Machine Learning Performance

1. Random Forest achieved the best overall performance.
2. Strong predictive capability with low error.
3. Balanced accuracy and generalisation.
4. Accurate predictions for normal operating ranges.
5. Increased deviation at high COD values (outliers).
6. Residuals are evenly distributed around zero, indicating no systematic bias.
7. The model shows strong generalisation with minimal overfitting.

Model Behaviour

The learning curves show that the tuned Random Forest model maintains a consistently high training score as data increases, indicating strong fitting ability.

The cross-validation score improves and stabilises with more data, suggesting better generalisation. Early variability decreases as the dataset grows, meaning performance becomes more stable. Overall, the model does not overfit and benefits from larger datasets, achieving reliable and well-generalised results. Plateau in both curves after about 300 samples, gains from adding more data are minimal, implying the model has largely saturated its learning capacity with the current feature set.

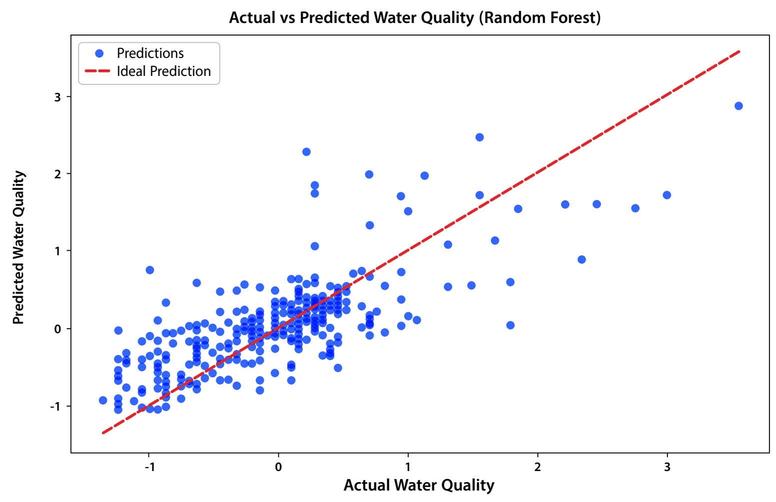


Figure 5. Actual vs predicted water quality scatter plot

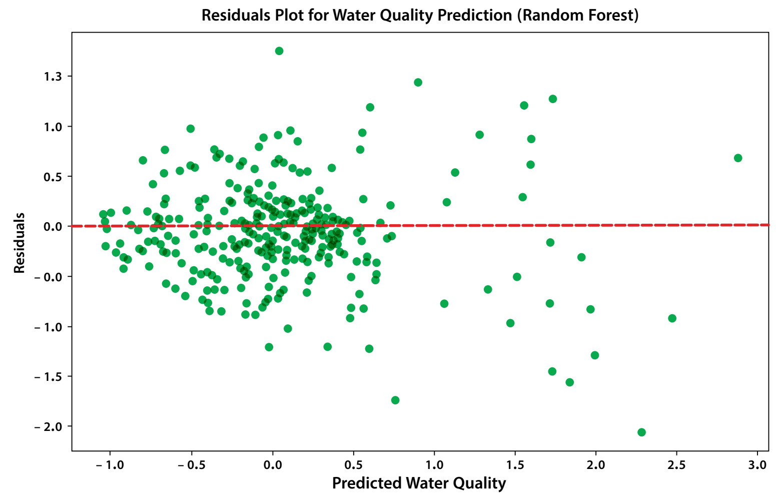


Figure 6. Residuals plot for water quality prediction

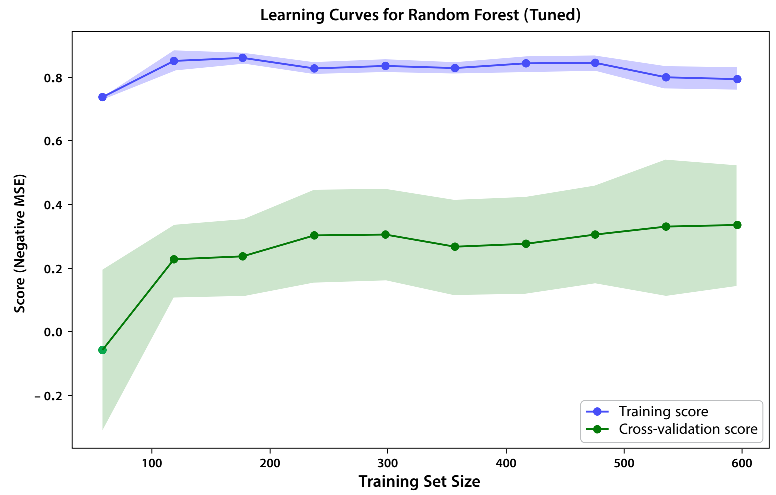


Figure 7. Learning curves for random forest (tuned) plot

Recommendations

Based on the findings, Integrating ML models into operational systems for real-time prediction to utilise it as an early detection system for process optimisation during normal operation. Furthermore, improve nitrification/denitrification during seasonal variations during upcoming shut down periods. Also, enhance prediction, accuracy and responsiveness. COD_in & phenols_in as primary control indicators that need to be controlled. Apply feature engineering & advanced tuning for further improvements and further enhancement to the data & sample collection methods.

Conclusion

This study demonstrates the successful integration of machine learning into refinery wastewater treatment. The Random Forest model provides reliable COD predictions, enabling proactive decision-making and improved operational control. The approach enhances environmental compliance, reduces operational costs, and supports sustainable refinery operations. With further improvements such as real-time data integration the system can evolve into a fully optimised, intelligent wastewater management platform.

Digital Transformation in Procurement and Contracts: **Bridging Efficiency and Governance**

With increased regulatory scrutiny, cost pressure, and global disruptions (such as the COVID-19 pandemic), the need to modernise procurement practices has become a top priority for organisations. Traditional manual systems no longer meet the demands for speed, transparency, or agility.

Abdulmohsen Al-Ali
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Commercial Dept.

Introduction

Digital Transformation in procurement and contracting refers to the strategic adoption of digital tools and technologies to automate, optimise, and enhance the procurement lifecycle, from sourcing to contract execution and supplier performance management.

This paper explores how Digital Transformation is reshaping the purchasing and contracting function across industries, with a focus on practical implementation within organisations. It outlines the key technologies driving this change, such as e-procurement platforms, contract lifecycle management systems, artificial intelligence, and blockchain. Drawing from real-world observations, the paper identifies major benefits including enhanced compliance, operational efficiency, and data-driven decision-making. It also discusses implementation challenges like integration with legacy systems, change resistance, and skill gaps. Finally, the paper presents a roadmap for organisations aiming to embrace digital tools for long-term value creation.

Traditional Procurement and Contracting Challenges

Before digitalisation, many organisations relied on paper-based or semi-digital procurement systems. Key challenges included:

1. Manual purchase requisitions and approvals.
2. Time-consuming contract drafting and reviews.
3. Inconsistent document storage and retrieval.
4. Poor spend visibility and data silos.
5. Delayed supplier onboarding and payments. These issues often resulted in missed opportunities, higher risks, and reduced operational efficiency.

Key Technologies Enabling Transformation

1- E-Procurement platforms
Digital Platforms provide end-to-end automation, from Desktop/Service requisitions to invoicing. These systems help standardise procurement workflows, improve compliance, and track key performance indicators (KPIs).

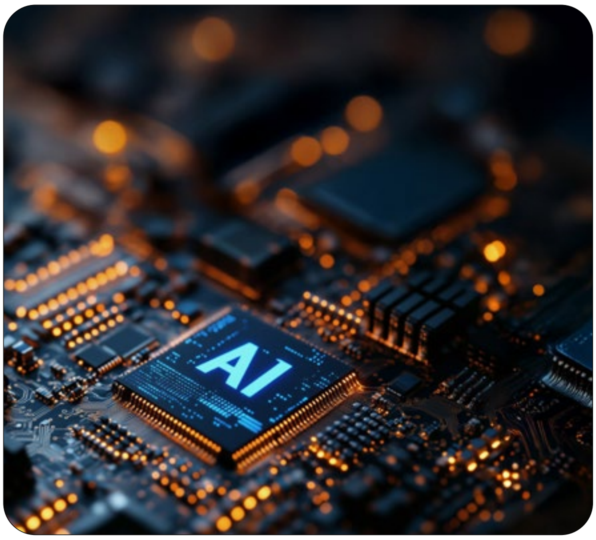
2- Contract lifecycle management (CLM)
CLM Platforms/Tools digitise the entire contract lifecycle. They enable version control, automated clause libraries, approval routing, and searchable repositories.

3- Artificial intelligence and analytics
AI-powered solutions help with spend classification, supplier risk analysis, demand forecasting, and fraud detection. Predictive analytics also support better decision-making during sourcing and negotiations.

4- Robotic process automation (RPA)
RPA bots handle repetitive tasks such as data entry, PO creation, and invoice matching. This reduces human error and frees up procurement professionals for strategic work.

5- Blockchain and smart contracts
Blockchain provides a secure, immutable ledger for contract terms and transactions. Smart contracts automatically enforce terms based on predefined conditions, reducing disputes and improving trust.

6- Digital signatures and cloud repositories
E-signature tools (e.g., DocuSign, Adobe Sign) streamline approvals. Cloud-based storage ensures remote access, version control, and audit readiness.



Benefits and Value Realisation

Organisations implementing digital procurement systems report:

Time savings:

Faster approval cycles and reduced procurement lead time

Transparency:

Real-time dashboards and audit trails

Cost reductions:

Improved supplier competition and better spend analysis

Risk mitigation:

Early identification of non-compliance or supplier issues

Compliance improvement:

Automated workflows ensure adherence to internal policies

Strategic focus:

Procurement teams can focus on value creation, not paperwork

Challenges in Implementation

Despite clear benefits, Digital Transformation comes with challenges:

Resistance to change:

Employees may be hesitant to adopt new tools.

Budget constraints:

High upfront costs may deter investment.

Legacy system integration:

Compatibility issues can delay deployment.

Skill gaps:

Teams may lack expertise in digital tools or data analytics. Addressing these challenges requires leadership buy-in, continuous training, and phased implementation.

Data quality:

Incomplete or inconsistent historical data can hamper migration.

Real-World Case Example

In my experience within a large organisation undergoing Digital Transformation in procurement and contracts, we implemented a CLM tool alongside SAP S/4HANA for procurement automation. Previously, contract approvals took 10-15 days. After automation, approval cycles dropped to 2-3 days. Moreover, by integrating spend analytics dashboards, we identified redundant suppliers and achieved 12% cost savings across indirect categories within one year.

Outlook

As technology evolves, future trends include:

1. AI copilots: Guiding procurement users in real-time.
2. Predictive contracting: AI forecasting risks and compliance issues.
3. Autonomous procurement: Self-driving sourcing events.
4. Digital traceability: Enhanced Environmental, Social, and Governance (ESG) compliance and supplier transparency.

Conclusion

Digital Transformation in purchasing and contracting is no longer optional - it is essential for competitiveness, compliance, and agility. By investing in the right technologies and managing change effectively, organisations can transform procurement from a cost centre into a strategic value driver. This transformation not only improves operational metrics but also empowers professionals to focus on innovation, strategy, and collaboration.

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Enhancing Control Systems: **DCS Mesh Network Integration**

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Mina Al-Ahmadi Refinery

Eng. Abdulaziz Al-Ajmi
Maintenance Dept.
Mina Al-Ahmadi Refinery

In the area of industrial automation, Distributed Control Systems (DCS) play a pivotal role in managing complex processes and ensuring operational efficiency. As industries evolve towards interconnected systems, the integration of DCS with mesh networks emerges as a transformative solution.

Introduction

DCS Mesh Network Integration represents a shift in control system architecture, offering unparalleled flexibility, reliability, and scalability. Unlike traditional point-to-point communication, Mesh networks enable nodes to communicate directly with each other, creating a resilient and self-healing network topology.

In Mina Al-Ahmadi Refinery (MAA), we faced the challenge of integrating the newly commissioned Gas Train 5 (GT-5) DCS network with the existing Gas Plant (GP) mesh network aimed to enhance reliability of the network. Also, the GT-5 Mesh Network Integration aimed to mitigate single points of failure, ensuring uninterrupted data flow and system operability. This redundancy feature significantly improves system resilience and minimises downtime, critical in mission-critical industrial environments.

Comparison: DCS Vs. IDCS

DCS is an automated control system that consists of multiple interconnected controllers distributed throughout a plant or process. These controllers work together to monitor and control different parts of the system, ensuring efficient and coordinated operation. On the other hand, integrated distributed control systems (IDCS) is an advanced form of a DCS that seamlessly integrates various automation and control functions into a unified system. It combines process control, safety systems, asset management, and enterprise-level data integration to enhance operational efficiency, reliability, and decision-making.

The DCS has certain characteristics. First, decentralised control - unlike a centralised control system, DCS distributes control tasks across multiple controllers, reducing the risk of a single point of failure. Second, real-time monitoring - it continuously collects and processes data to optimize performance and detect faults. Lastly, communication networks - controllers and field devices communicate through industrial networks like Ethernet, PROFIBUS, or Modbus.

Meanwhile, the following are advantages of the IDCS compared to traditional DCS:

1. Centralised and decentralised control- Provides flexibility by allowing both local (centralised) and plant-wide (centralised) control.
2. Seamless communication - Uses standardised communication protocols (e.g., OPC, Modbus) to ensure smooth data exchange across different systems.
3. Unified architecture - Integrates multiple control functions such as process automation, safety systems, and asset management under a single platform.

IDCS Advantages

Advanced Analytics and AI Integration

The combination of sophisticated data analysis techniques with AI technologies to derive deeper insights, automate decision-making, and optimize business processes. By leveraging machine learning, predictive modeling, and natural language processing, organisations can uncover patterns, forecast future trends, and make data-driven decisions with greater accuracy and efficiency.

The integration of AI with advanced analytics enhances the ability to process large volumes of complex data in real-time, enabling businesses to adapt swiftly to changing conditions and gain a competitive edge. Additionally, it supports personalised customer experiences, improves operational efficiency, and drives innovation across various industries.

Cybersecurity and Reliability

Cybersecurity in Mesh networks involves safeguarding data transmission, preventing unauthorised access, and ensuring the privacy of sensitive information. Since each node in a mesh network can potentially be an entry point for attackers, robust encryption, secure authentication mechanisms, and intrusion detection systems are essential to protect the network from cyber threats.

Reliability refers to the network's ability to maintain continuous operation even in the face of node failures, interference, or network congestion. Mesh networks are inherently resilient due to their self-healing nature, where data can reroute through alternative paths if a node becomes unavailable. However, the reliability of these networks depends on constant monitoring, efficient routing algorithms, and redundancy to ensure minimal downtime and optimal performance.

Scalability and Flexibility

Scalability in mesh networks refers to the ability to expand the network seamlessly as the number of connected devices or nodes increases. Unlike traditional centralised networks, mesh networks can accommodate a growing number of devices without requiring significant changes to the existing infrastructure. As more nodes are added, the network automatically adjusts to include these new devices in its routing paths, ensuring consistent performance and coverage.

Flexibility in mesh networks pertains to their ability to adapt to diverse environments and use cases. Mesh networks do not rely on a central hub or infrastructure, which allows them to operate in dynamic and decentralised settings. This flexibility enables easy reconfiguration and optimization of the network, whether for different geographic areas, shifting requirements, or handling varying traffic loads. Additionally, mesh networks can be deployed in a variety of environments, including urban, rural, or challenging terrains, making them suitable for a wide range of industries and disaster recovery.

DCS Mesh Network Case Study in MAA Refinery (GT-5)

List of Activities Attended During the Network Integration

- Firmware update and reconfiguration of GT5 DCS Mesh switches are per the existing Gas Plant Control Room (GPCCR) philosophy.
- Restore of Galaxy Backup in offline setup.
- Integration of GT5 Mesh switches, DCS servers and workstations to existing GPCCR DCS Mesh network.
- Reboot of all GT5 control processors and download from restored galaxy backup.
- Firmware update of all FBM228, FBM233 and all devices were taken online.
- Integration of GT5 graphics with all existing DCS servers and workstations and vice-versa, and integration of GT5 DCS login environments with existing GPCCR DCS servers, workstations and vice-versa.
- Integration of GT5 PIN network to existing GPCCR PIN network.

Benefits of GT5 Network Integration

- A communication pathway has been established between the GT5 Instrument Satellite House (ISH) and the main GPCCR.
- Gas management philosophy methodology was developed and achieved, enabling the regulation and control of main feed gas stream distribution across the 5 gas trains within MAA Refinery.
- The optimization of hardware and cabling in the Advanced Process Control (APC) Project has enabled the utilisation of the same Laboratory Information Management System (LIMS) server and Production Control Website (PCWS) server, enhancing efficiency and resource management.
- The initial shutdown plan was scheduled for 15 days; however, opportunities for improvement were identified in the Foundation Fieldbus device configuration, allowing the completion of the job within 11 days.
- From a cybersecurity perspective, KNPC is implementing a new policy focused on enhancing IT/OT cybersecurity measures. As part of the DCS network integration, this initiative is expected to reduce number of hardware such as "firewalls and switches" while streamlining and improving the efficiency of security patch updates across the KNPC network, thereby strengthening overall system security and resilience.
- The integration of the DCS mesh network will play a crucial role in enabling the virtualisation of operator and engineering workstations. This represents a significant advancement towards the digitalisation of the oil and gas industry, enhancing operational efficiency and technological innovation.

Summary

The Growing Role of DCS Mesh Network Integration in Modern Industries Concerns

The integration of DCS mesh networks is rapidly transforming industrial operations, offering enhanced connectivity, real-time data exchange, and improved system resilience. By leveraging DCS mesh networks, oil and gas industries can enhance cybersecurity, optimize network performance, and facilitate seamless communication between IT and OT environments. Moreover, this integration aligns with the broader shift towards digitalisation, ensuring industries remain competitive in an increasingly technology-driven landscape.

Considering Integration for Operational Efficiency

Organisations should assess their existing infrastructure, identify potential integration opportunities, and develop a roadmap for a smooth transition. By adopting this technology, companies can reduce costs, improve system reliability, and enhance overall productivity. The shift towards digitalisation and automation is inevitable, and early adoption of DCS mesh networks will position businesses at the forefront of industrial innovation.

Control Room Design: **The Essentials and Challenges**

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In today's context, where human ergonomics, safety, and wellbeing are paramount, designing a Control Room requires careful consideration of numerous criteria. Rapidly evolving technologies further increase the complexity of these requirements.

Introduction

KNPC has celebrated the 65th anniversary of its establishment - a journey marked by outstanding growth and continued technological advancement.

Mina Al-Ahmadi Refinery (MAA) commenced its actual operations in the year 1949. Over the years, multiple process units were added, technological upgrades implemented, and the Refinery gradually expanded to its current scale.

With this growth, the need to expand existing Control Rooms—or construct new ones—to operate these units becomes critical. One of the needs of the hour for the MAA Refinery is a new central Control Room for the gas plant facilities. KNPC has categorically begun the study phase for the new GPCCR with the feasibility study successfully being completed and commencement of the FEED.

Key Parameters

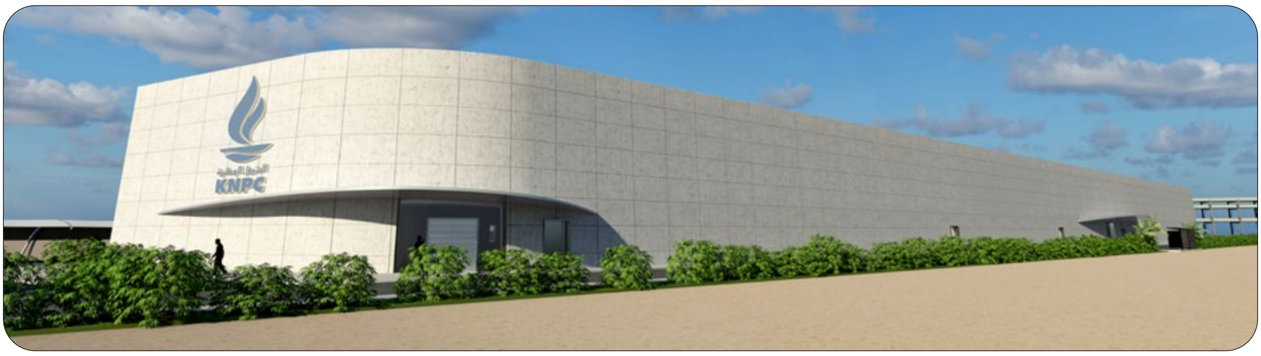
Designing a Control Room is a multidisciplinary endeavour that extends far beyond arranging monitors on a desk or on the walls. It involves creating an integrated system of people, processes, hardware, networks, and the physical environment. At KNPC, we are developing a state-of-the-art Control Room for our gas operations within the MAA Refinery. During designing and engineering the Control Room, several parameters were taken into consideration to create an efficient, safe, and technologically advanced model keeping up with the modern industrial standards. The design had to be carefully drafted based on comprehensive functional analysis and stakeholder requirements to ensure optimal operational efficiency, ergonomic compliance, and strategic facility performance.

Let us look at the key parameters where the emphasis lies:

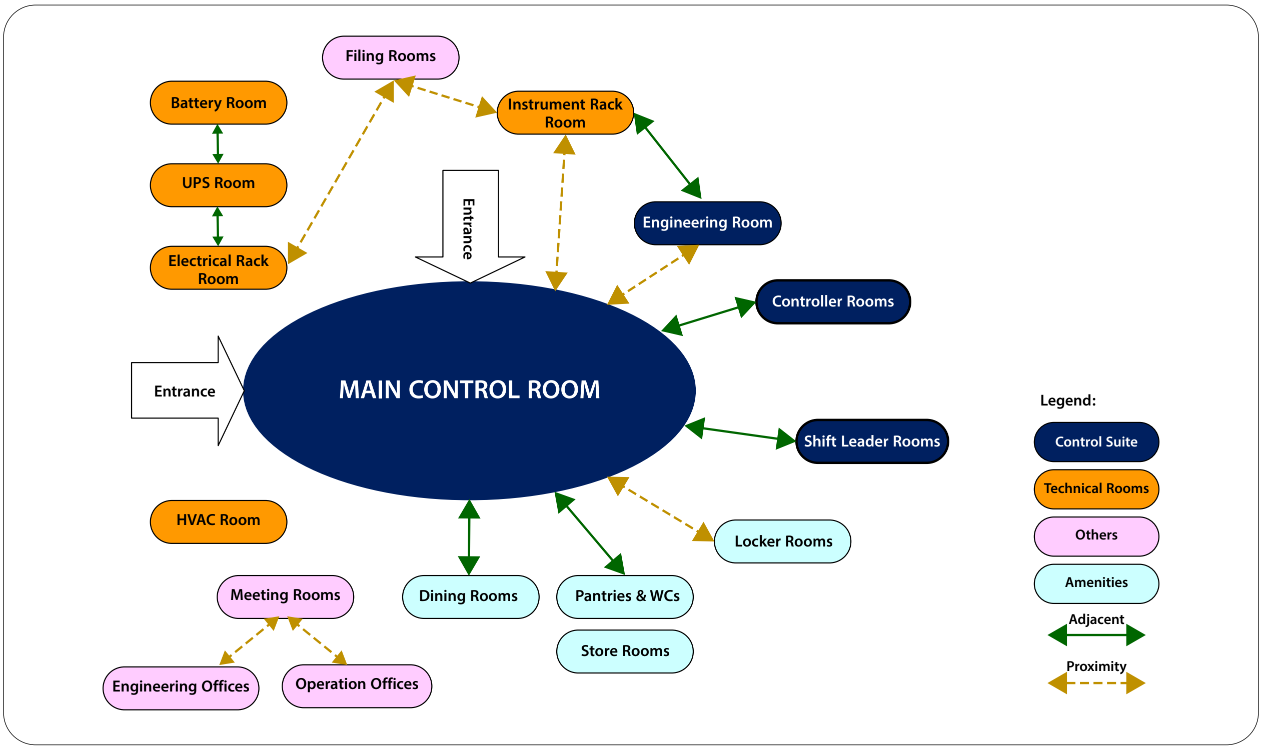
1. Real Estate
identifying an appropriate area within the 75-year-old refinery was one of the primary constraints experienced in a new Control Room development. The identified area must consider future scalability, access roads, emergency evacuation routes, communication connectivity, and environmental factors such as soils load bearing capacity and contamination quotient.

Another key consideration is the hazardous area classification. The control building shall preferably fall outside the extreme hazardous area zones limiting high explosion and fire risks. This is particularly difficult to achieve in older refineries where process units were built closer as the safety standards were not defined by today's standards at the time of their commissioning. It is ideal that the identified plot is outside the Quantitative Risk Assessment (QRA) envelope.

Another important criterion is operational proximity. Globally, there are Control Rooms being operated far from the actual site area, some running into several kilometers like offshore facilities, remote rigs etc. In KNPC, however, the location of the Control Room is preferred not to be too far away from the areas of operation as it enhances decision making, better communication and faster response time during emergencies.



Artistic rendering for the new GPCCR



2. Functional and Adjacency Assessment
The control building serves as the brain of the gas operations and as a premier operational hub which requires a methodological design complying to international and local standards while also incorporating the best practices established for safety and efficiency. It is not merely space allocation, but a systematic functional assessment is required to define the purpose, occupancy, and operational needs to optimize interdependence and workflow dynamics among its occupants and facilities.

The control building must be engineered to support role-based functions like:

Operations: The primary occupants of this building engaged in the control suite to operate the plant.

Technical: Space for rack rooms, network, servers & telecom connections, electrical & HVAC equipment to house critical infrastructure.

Support: Technical offices, meeting rooms, crisis management centre etc.

Other Amenities: Basic essential facilities like pantries, dining, ablution, lockers, recreational rooms vital for personnel well-being of workers.

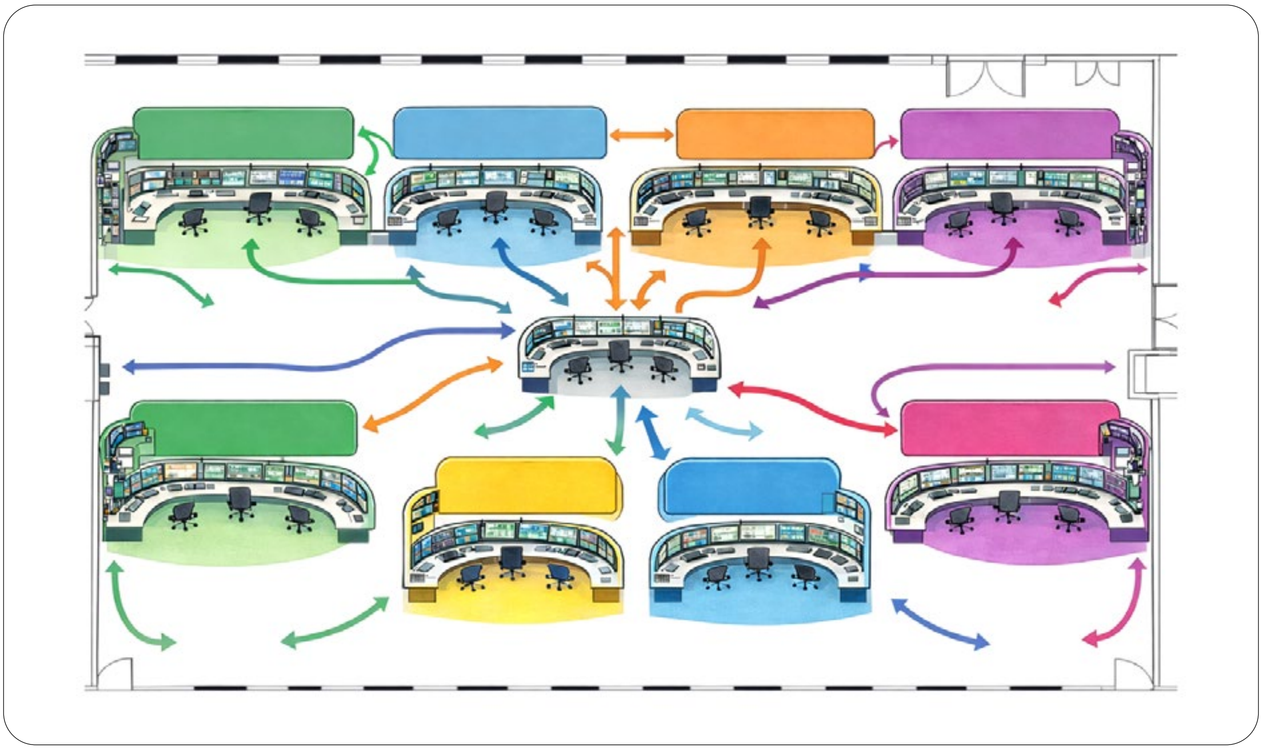
A fundamental step in functional assessment is to have a functional and role analysis and study the adjacency requirements between these distinct groups.

One method to analyse this is through a bubble diagram representation.

3. Ergonomic Requirements
A Control Room is on a 24/7 operation, so it is imperative to create a design which minimises fatigue, errors or pose any health risks to the operators along with aiding in a better response time during abnormal conditions. The shape, dimensions, and configuration of the control building must be precisely designed considering physical, physiological, and cognitive factors related to workplace design with stress relief and anti-fatigue considerations. Compliance to international standards such as ISO 11064: Ergonomic design of control centres ensures this. Some of the key areas where the focus lies are:

a. Control Suite Layout
As several areas of a plant are controlled and operated within the same ballroom, the workflow analysis between each control station is vital. Space planning should be done such that it makes communication easier between area controllers of different console stations.

b. Traffic Flow
The traffic flow within the building also is important. It should be made sure that



smooth and unobstructed traffic flow shall be there to support both routine operations and emergency response. Movement near the console stations must be minimised to reduce distractions and ensure no interference with critical tasks.

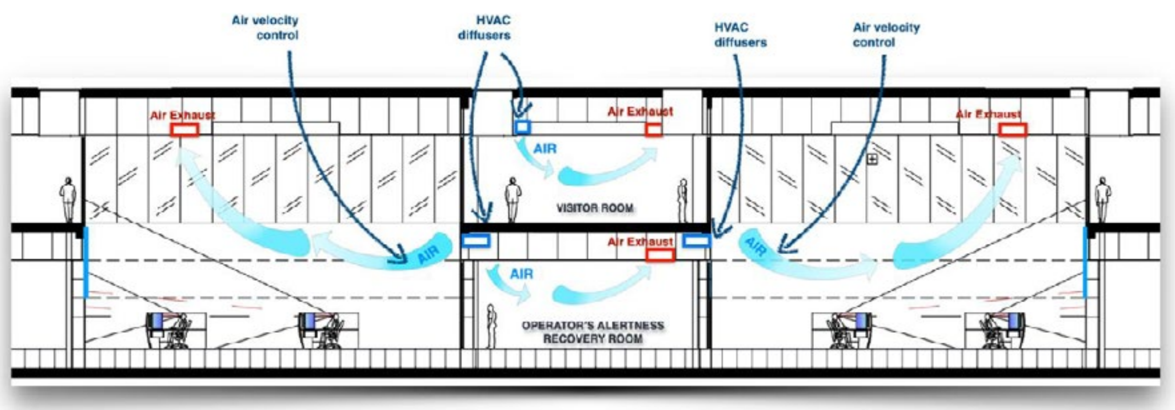
c. Workstation and Console Design
Consoles should be fully adjustable - allowing operators to modify height, viewing angles, and reach distances - to suit a wide range of body dimensions. Screen placement must follow optimal ergonomic viewing zones to minimise neck and eye strain. The design should also integrate cable management, and space for documentation and communication devices without cluttering the operator's workspace.

d. Lighting and Acoustics Analysis
Proper lighting zones are required to be created for different parts of control building like operator console area, walkways, meeting rooms, offices etc. for comfortable and non-distracting illumination to support better performance. Features like glare control, illumination levels, dimming facilities, color quality, daylight control and emergency lighting shall be individually studied.

Similar principles apply to acoustic management as well. The design shall incorporate noise mitigation measures to ensure acceptable acoustic conditions during peak activity periods such as shift changes, abnormal operations, and emergency situations. In addition, continuous background noise generated by computers, control equipment, servers, and adjacent plant areas shall be controlled to maintain speech intelligibility and ensure clear audibility of alarms and annunciators.

e. HVAC Requirement
The indoor environmental conditioning of Control Room buildings shall be designed to provide a safe, healthy, and thermally comfortable working environment for all operating personnel. The HVAC system shall maintain prescribed limits for temperature, relative humidity, and indoor air quality under all modes of operation. Adequate provision of fresh air shall be ensured to support occupant well-being, accommodate periods of increased occupancy density, and allow for future operational and functional flexibility.

4. Control Systems
Another fundamental challenge in modernising systems in existing Control Room is integrating various legacy systems which the users are very comfortable using. Existing systems may use different communication protocols that require propriety gateways to translate between old and new platforms.



Some of the key integration obstacles are:

a. Hardware Obsolescence
Critical legacy components are no longer manufactured or supported, making it difficult for the refinery's to operate and maintain the systems on a long run. This creates urgency around migration decisions.

b. Data Integration
Unifying historical data from different systems into a common historian requires normalising different timestamps, data formats, and scan rates while managing gaps during migration.

c. Cybersecurity
Legacy systems usually lack modern security features, calling for creative solutions, for instance, implementation of unidirectional gateways that allow monitoring data only but prevent writing commands.

The solution typically involves a mixed and phased approach rather than complete replacement. In MAA we have planned a mirroring concept with newer technology.

5. Human Factors
Beyond technical challenges, the human factor hurdles lie. Operators with years of experience have a deep knowledge tied to the existing panel layouts, where they can scan entire process areas with a glance. They would now need to change how they interact with processes they know so intimately. Screen-based interfaces pose a new challenge, turning instantaneous reflexes into hierarchical navigation tasks such as opening a display, drilling down, clicking through menus etc. Response times initially increase during the learning curve, legitimately concerning operators responsible for safety-critical operations.

Maintaining operations during this entire process is also a tricky stage. Refineries prefer not to shut down for migration. Approaches like unit-by-unit migration or short parallel operation periods are quite common with meticulous hot cutover plans and procedures.

Success of this also requires treating this as a cultural transformation, not just a technical project. When management provides adequate training time, listens to feedback, and empowers operators to fix issues rather than work around them, adoption accelerates significantly.

Conclusion

Building a modern control room in brownfield refineries presents significant challenges demanding a comprehensive strategy for operational efficiency, safety, and technological growth. Successful modernisation ultimately hinges on strategic project management along with a strong management commitment. We at KNPC are on this journey to achieve these marvels for a productive future and look forward to implementing the best practices for the new Gas Plant Central Control Room (GPCCR).

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