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REFINING
GAS PROCESSING
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DIGITAL TWINS

REFINERY WASTEWATER CHALLENGES

CDU OPTIMISATION PREFLASH DRUMS & TOWERS

CONTROLLING BIOFILM FORMATION

Revolutionising refining with digital twins

Exploring applications and outputs across the refinery landscape

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Refiners are at the crossroads of innovation and challenge. They are facing disruptions ranging from oil price volatility to the complexities of the global energy transition. Adding to this complexity, Offshore Technology claims India is expanding its pipeline network to more than 29,600 km by 2025. This significant expansion is roughly three-quarters of the Earth's circumference. As the industry confronts these uncertainties, securing the integrity of this expanding pipeline infrastructure becomes crucial for meeting the nation's growing energy demands while reducing risks and accidents that can harm people, profits, and property.[1]

Navigating new refining challenges

To navigate these new challenges, the refining industry is revamping how it produces, uses, and manages energy.[2] Although existing assets have data acquisition capabilities, the hurdle lies in reviewing, cleaning, and assessing this data. This process is necessary to determine both current and future operating conditions, as well as meet safety and environmental regulations.

In this journey, Indian refiners are in the process of implementing digital twins across various refinery process units for long-term sustainability.[3] This initiative centres around creating digital twins for diverse applications, which provides real-time visualisation of key performance indicators (KPIs) and benchmark parameters. By using digital twins, refiners can improve the plant's efficiency and productivity while reducing miscommunication, data waste, and labour costs. Essentially, digital twin technology is revolutionising the way refiners operate and paving the way to long-term profitability.[4]

Furthermore, it is evident that all aspects of an entire refining supply chain are highly interrelated and complex. Thus, integrating digital twins into the supply chain delivers added value, too, by optimising processes, energy consumption, and control applications such as real-time optimisation (RTO) and advanced process control (APC) systems. In the supply chain, these applications help bridge the gap between forecasting and actual operations.[4] Validating these gaps, or delta vectors, uncovers the disparities between the planned and actual operations in terms of demand, inventory, and production. By validating these delta vectors, supply chain managers can quickly assess and address gaps in their models and processes to accommodate changes in inputs and outputs.[1]

In regard to process optimisation, which is integrated with supply-side optimisation for power, steam, and utility balances, energy demand takes centre stage. The comparison between linear programming (LP), actual data, and simulation enables automated vector updates and model recalibrations via artificial intelligence (AI) and machine learning (ML) methods.

The following discussions explore various applications, including KPI visualisation, production accounting, LP model updates, process optimisation, real-time optimisation, and corrosion monitoring. The digital twin architecture includes connecting process models through open platform communications unified architecture (OPC UA) with historians to ensure proper calibration.

Digital twin technology

Digital twins offer a solution to transform the oil and gas industry by improving efficiency and reducing risk. According to researchers,[5] these virtual models of physical assets seamlessly connect with real-time data across assets, columns, reactors, pipinmg, and equipment. Despite changes in crude quality, catalyst composition, and process conditions, digital twins continuously analyse industrial data to predict and optimise processes.[4] Their perpetual operation brings multiple benefits, such as asset monitoring in planning and scheduling studies, refinery-wide flow sheeting, real-time optimisation, and more.

Furthermore, digital twins set benchmarks for both the quantity and quality of units. These benchmarks are then transmitted to the RTO/APC layer for optimisation on a global scale.[6] This iterative process involves ongoing validation and adjustments to maximise benefits derived through the APC in a closed loop. The APC, armed with its dynamic process model, aims to stabilise operations and reduce fluctuations. It effectively implements the desired setpoint from the RTO to achieve closed-loop optimisation.[5] The optimiser identifies the optimal operational state and communicates it to the APC.

Implementing a digital twin starts with identifying possibilities and choosing a pilot configuration with the highest ROI. After implementation, the digital twin becomes an integral part of the enterprise's digital backbone.[4] The final step involves monitoring the value created and modifying the digital twin to maximise economic benefits.

Refiners apply digital twins in various applications to

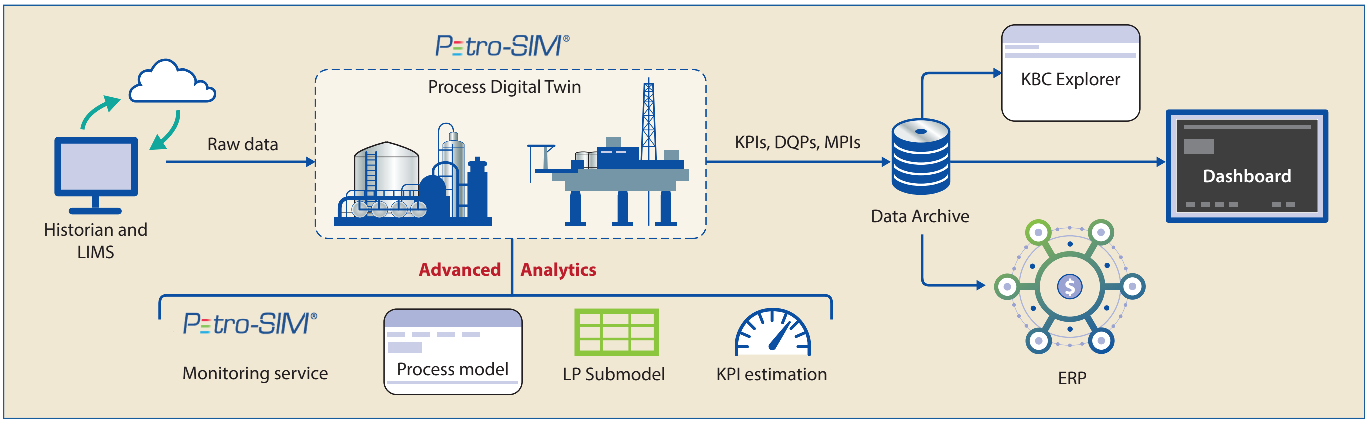

Figure 1 Digital twin architecture

improve plant performance. These applications include visualising KPIs for performance tracking, reconciling data in production accounting, updating LP models in the supply chain, optimising processes to improve yield and energy, conducting real-time optimisation through quick gain calculations, and managing corrosion to monitor equipment and system degradation. These applications underscore the value of digitalisation in the refining process and are addressed in the remainder of this study.

Digital twin architecture

The digital twins are process models connected through OPCs with historians such as IP.21, Exa Quantum, OSI PI, or any other real-time data gateways, as shown in **Figure 1**. The models are calibrated using test data to ensure energy and mass balance accuracy. After calibrating the model, it is scheduled to run, and the results appear on dashboards. Other applications use these to generate advanced analytics.[4]

The success achieved from this system depends on whether the model is accurate and current. An outdated model limits the operation's potential, resulting in value leakage, lost opportunities, and substantial financial costs.

Visualisation: Enhancing KPI management

In the refinery, KPIs act as a compass, guiding performance tracking of key metrics such as temperature, pressure, equipment status, and more. Digital twins, adept at tracking and measuring KPIs, calculate intrinsic parameters such as yields, energy consumption, and column performance such as flooding, heat exchanger fouling, furnace efficiencies, coking tendencies, and emissions along with the benchmark parameters. Closing these gaps between the actual measurements and the benchmarks adds value.[7]

KPI management uses a strategic approach that aligns with the company's goals to optimise plant and equipment performance. This approach ensures measurable progress. Derived from plant measurements, KPIs offer real-time insights into critical parameters such as unit throughput, feed, and product quality.

Furthermore, calculations address yields and fractionation efficiency to identify process improvement opportunities. The intrinsic layer, estimated via a process digital twin, dives into issues such as column flooding, exchanger UA and fouling factors, and coking inside heater tubes. Using these intrinsic KPIs, operators can maximise asset utilisation and proactively improve the plant's efficiency. Essentially, this system not only evaluates performance holistically but also provides insight to continuously improve individual assets or the entire complex.[7]

Figures 2 and **3** illustrate trends in product yields and intrinsic parameters, respectively. Figure 2 indicates the product yields vs timeline such as day/month. Figure 3 shows the intrinsic parameter limits and trends for jet flooding and downcomer backup, which are regularly calculated.

Production accounting: Single version of the truth

The typical production accounting digital twin serves as the facility's single version of the truth, laying the foundation for the hydrocarbon balance and loss control initiatives as shown in **Figure 4**. The system not only generates the hydrocarbon balance accurately, but it also detects losses.

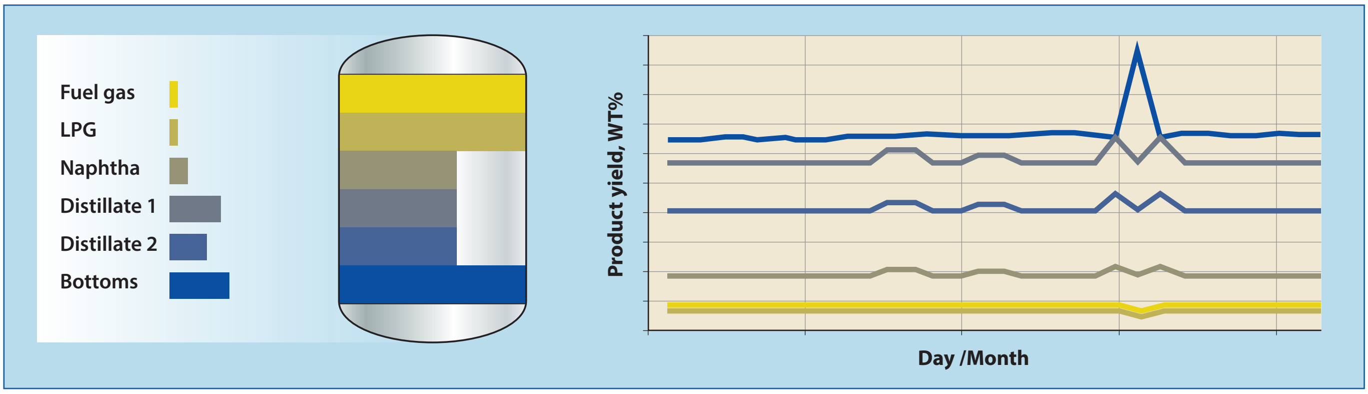

Figure 2 KPI product yield (wt%) trends

It provides a systematic approach to reconciling data input errors. Reconciliation entails distributing mass imbalance errors across streams, adjusting specific streams to achieve a close mass balance, and using site-wide tools to seamlessly close the balance across assets.[5]

Additionally, the process digital twin enhances operational efficiency through various capabilities. First, it ensures a precise elemental balance apart from mass considerations, providing a comprehensive understanding of the hydrocarbon processes. Moreover, it contains details about plant and tank farm operations, offering insights into movements critical for effective management. As a result, the digital twin helps uncover gross errors early in the business process, ranging from data entry errors and instrument failures to missing movements. With automatic logic, it uses coke production and adapts to flow variance, ensuring uninterrupted production even during outages.

Supply chain – LP model updates for robust planning

In refinery and petrochemical complexes, LP models play a vital role in assessing crude selection, yields, and gross margin via optimisation functions. Despite their utility, these linear models often face challenges due to infrequent updates in sensitivities related to feed, severity, and product qualities. This discrepancy between model predictions and actual performance, particularly at the end of back casting, can negatively impact operational efficiency.[4]

Traditional LP models used for planning, scheduling, and optimising assets lack continuous validation. This deficiency, often performed by individuals, creates inaccuracies that contribute to suboptimal operations. To overcome these challenges, the digital twin continuously tracks asset performance. Thus, all stakeholders get a comprehensive view of asset performance, including optimum operating targets, enhanced scheduling, and inventory cost savings.

Additionally, digital twins not only automate complex work processes such as kinetic model calibration and validation but also leverage AI and ML methods to automate workflows, check the application's health, validate AI recalibration recommendations, and validate the accuracy of the vectors. As shown in **Figure 5**, the automated model maintenance tool determines when the model needs to be recalibrated and establishes protocols for validating the model. The result is ongoing health score tracking, data quality analysis, and actionable email alerts.

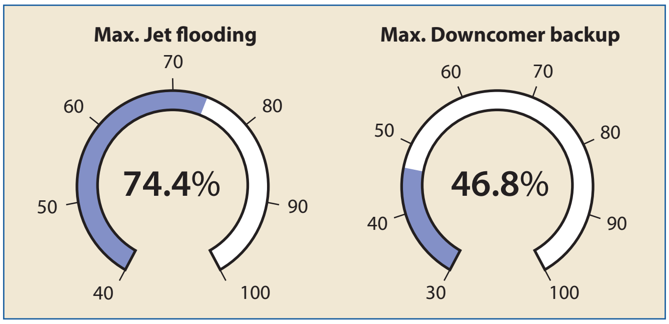

Figure 3 Intrinsic parameters monitoring

Process optimisation: Bridging gaps and identifying opportunities

Process optimisation can be achieved using a digital twin to identify gaps between actual and benchmark performance during plant operation or the design stage. The gaps are analysed for corrective actions such as changing operating parameters or modifying equipment, piping, or instrumentation. Digital twin applications for process optimisation include:

- What-if analysis, debottlenecking, and optimisation
- Constraint management
- Molecular management
- Unit/equipment optimisation
- Product blending and stream routings
- Identify margin improvement opportunities
- Screen opportunities
- Continuously track benefits for each implemented opportunity.

Based on the authors' experiences, the digital twin of an integrated refinery and petrochemical complex with a multi-feed steam cracker complex helped identify operational improvement opportunities exceeding 100 million USD and Capex savings tipping 100 million USD during the design review of its configuration.

Real-time optimisation: Dynamic control for operational excellence

In traditional distributed control systems (DCS), the process parameter from specified boundaries is common. In APC,

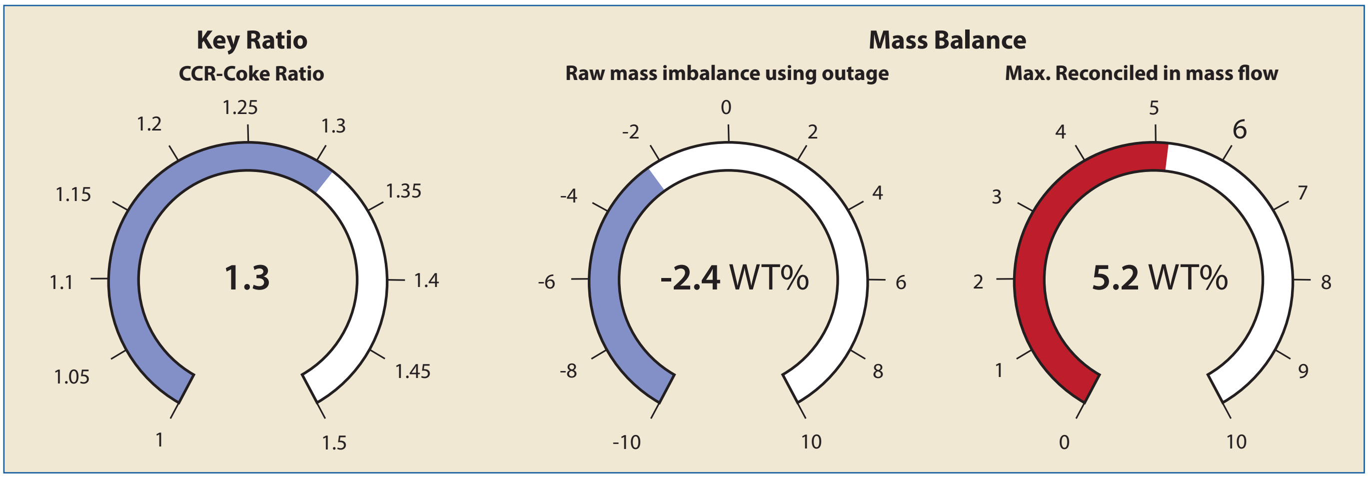

Figure 4 Key performance indicators

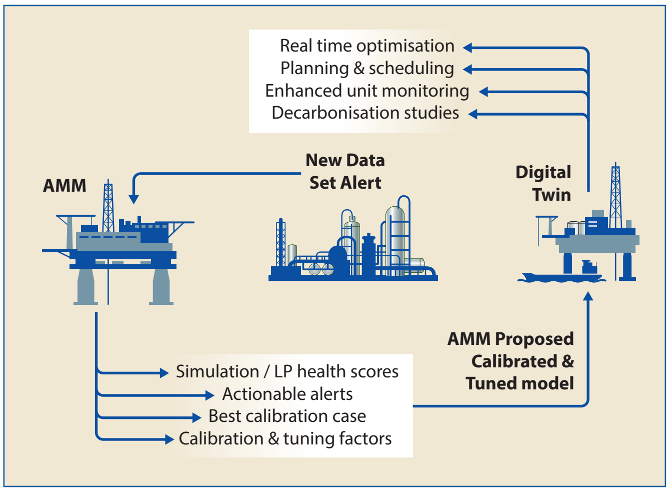

Figure 5 Automated model maintenance

the process is maintained at desired operating conditions by reviewing process constraints, reducing process variability.

During actual plant operations, equipment availability, economic conditions, and process disturbances result in changes in optimum conditions, as shown in **Figure 6**. Hence, the optimum operating conditions need to be re-calculated in real time. The RTO of set points requires two models: the economic model and the operating model. The economic model functions to minimise costs while maximising product values, and the operating model is a steady-state process model to identify the operating limits for the process variable.

Case study: Showcasing digital twin applications

This case study minimises corrosion for a refinery overhead system. As part of their digitalisation journey to improve asset reliability, this client sought a centralised corrosion monitoring system. To address corrosion issues in the crude distillation units' (CDU) overhead system, KBC (A Yokogawa Company) deployed a corrosion digital twin.

The following objectives were set to guide the deployment of a digital twin to monitor corrosion in the refinery's CDU overhead section and optimise operations:

❶ Online prediction and monitoring of corrosion indicator parameters.

a. Ionic dew point temperature and pH
b. Salting point temperature
c. Aqueous phase condensation temperature and pH

❷ Optimise NH_3 injection flow rates
❸ Optimise wash water rates
❹ Generate integrity operating envelopes
❺ Estimate corrosion rates.

Corrosion monitoring: Guarding infrastructure integrity

Corrosion in CDU overheads caused unplanned and costly unit outages.[8] Eliminating or minimising corrosion in the overhead system of CDUs was challenging, as it could lead to pipe leaks. This corrosion stemmed from aqueous corrosion attributed to hydrogen chloride forming from hydrolysis of inorganic chlorides in crude preheat and furnace processes. Factors such as ammonium and/or hydrochloride salts that absorb moisture often cause corrosion above the dew point. Mitigation strategies involved optimising the injection of chemical agents or dew point control in the overhead system. This complexity made the overhead system one of the most vulnerable parts of each distillation unit. As shown in **Figure 7**, the corrosion digital twin provided a comprehensive solution that consolidated processes as well as chemical and corrosion data to streamline monitoring from a single location. The corrosion control delivered the following benefits:

❶ Minimised corrosive conditions
❷ Prevented excessive corrosion, thereby extending the service life of the pipe and process equipment
❸ Reduced and prevented unpredictable shutdowns or accidents
❹ Cut maintenance costs.

The corrosion digital twin achieved these outcomes by tracking the following parameters:

- Ionic dew point temperature
- Salting point temperature
- Aqueous phase condensation temperature and pH
- Neutralising ammonia injection rate
- Boot water pH
- Wash water injection rate.

An electrolyte-based fluid package with the proprietary OLI and Petro-SIM digital twin of the CDU overhead was developed to demonstrate the capabilities of a corrosion-monitoring digital solution. It provided key information to confirm corrosion mechanisms, rates, and comprehensive operational guidelines.

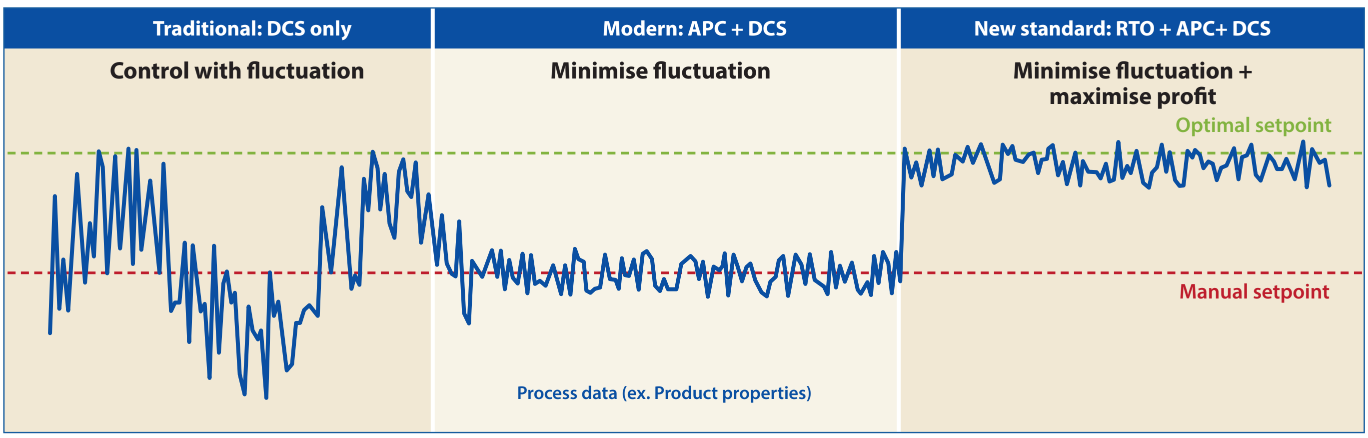

Figure 6 Control systems

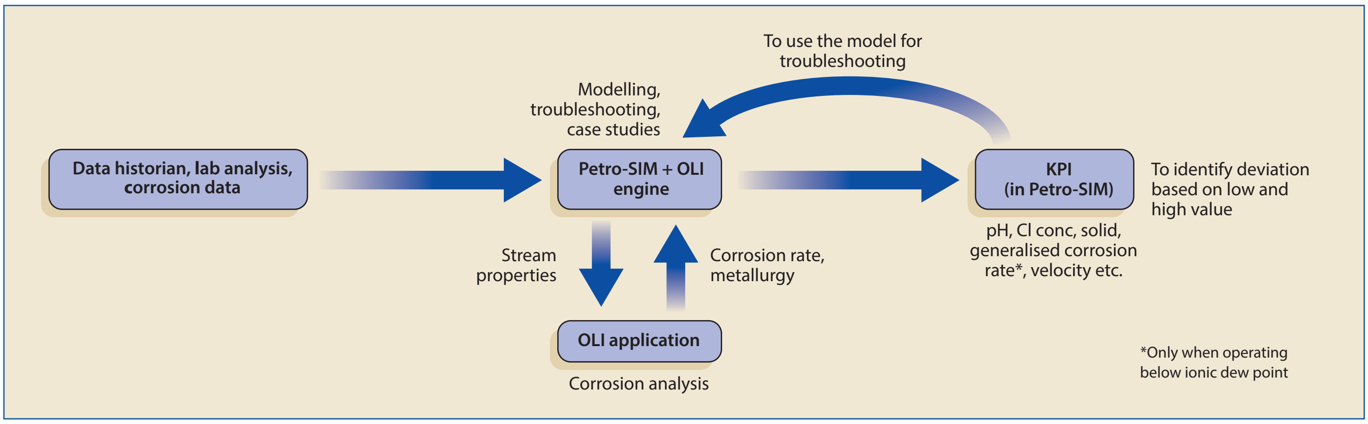

Figure 7 Corrosion digital twin

Conclusion

Standing at the crossroads of innovation and challenge, refiners face the complexities of the refinery and petrochemical industry. At this moment, KPIs emerge as valuable tools that monitor critical metrics such as temperature, pressure, and equipment status. These metrics not only provide insights but also serve as catalysts for innovation, helping refiners navigate the intricacies of yields, energy variances, column performances, and more.

Refineries and petrochemical plants are increasingly adopting digital technologies. One such tool, the digital twin, has proven to be a multi-faceted solution for both operational and design stages based on our experience. In this article, we present a case study of a refinery that benefited from digital twin applications, including:

- KPI visualisation incorporates intrinsic parameters like flooding and heat exchanger fouling characteristics
- Production accounting systems leverage mass balances and elemental balances to identify and address real losses within the production process
- Supply chain planning systems update LP vectors to represent non-linear sensitivities for more robust supply chain planning
- Production optimisation closes gaps based on benchmarking parameters to improve gross margins
- Real-time optimisation continuously calculates gains by optimising set points in real time
- Corrosion monitoring minimises corrosion rates and implements corrective actions to prevent pipe corrosion, ensuring the longevity and reliability of the infrastructure.

These applications emphasise the wide-ranging benefits that a process digital twin simulation software offers refiners, demonstrating its potential to revolutionise various aspects of plant operations and design.

This point of convergence should not be seen as a period of uncertainty. Rather, it represents a strategic juncture where the industry holistically assesses its overall performance and implements strategies for continuous improvement. It serves as a roadmap that motivates the industry to drive toward a sustained state of excellence.

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