Enhancing refinery profitability through rigorous catalyst evaluation

The role of independent catalyst testing offers unbiased assessments crucial for unit performance and quality

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In the complex world of petroleum refining, catalysts are integral to refining processes, enabling the conversion of crude oil into high-value products while significantly impacting operational efficiency and financial performance. Given the substantial costs associated with catalyst acquisition, typically ranging from $10 to $20 million, robust evaluation methodologies are essential for making informed decisions that align with production goals and market demands.[1]

Independent testing plays a pivotal role in this evaluation landscape, offering unbiased assessments that are crucial for identifying catalyst performance issues and ensuring quality. By engaging external experts, refineries can uncover defects that internal teams may overlook, thereby optimising catalyst performance. Despite their importance, many refiners fall into common pitfalls when selecting catalysts, leading to suboptimal performance and reduced profitability.[2]

In summary, rigorous catalyst evaluation is paramount for enhancing refinery profitability. By implementing best practices in catalyst management, refiners can not only improve operational efficiency and reduce costs but also ensure compliance with evolving environmental standards and market expectations. The ongoing advancements in catalyst technologies further emphasise the need for independent testing.[3]

Rigorous catalyst evaluation

The choice of catalyst affects both daily operations and long-term planning. As catalysts play a vital role in refining processes, their selection directly influences the refinery's production goals and overall financial performance. A well-executed catalyst evaluation ensures refineries operate with the most effective catalyst, maximising refining margins and profitability while minimising operational risks.

When selecting catalysts, refiners consider multiple factors, including expected performance, cost, guarantees, technical support, and their past experiences with potential suppliers. Key performance parameters are rigorously analysed, such as activity, yield selectivity, cycle life, deactivation rates, hydrogen consumption or production, and product properties.

To enhance evaluation accuracy, the process usually involves comparative catalyst testing in pilot plants under conditions that closely resemble commercial operations. This practice allows refiners to assess the economic implications and performance capabilities of different catalysts, ultimately selecting the one that best meets their operational needs.[1]

Rigorous catalyst evaluation not only optimises performance but also significantly impacts the economics of refinery operations. By improving yield and efficiency, effective catalyst selection can lead to substantial cost savings and increased profitability.

Mistakes due to lack of testing are not uncommon, and some are very expensive. For example, in one US hydrocracker, switching from the usual feed to deasphalted oil increased the catalyst deactivation rate by six-fold. In another example, a new catalyst increased middle distillate yields in a diesel-oriented hydrocracker by 5.6 wt%. The difference was so dramatic that it debottlenecked the entire refinery.[1]

Advantages

Independent catalyst testing is the best practice for rigorous catalyst selection. It provides an unbiased evaluation of performance, ensuring that refiners select the most effective catalysts for their units. The benefits include:

- Providing actual performance data, uncovering catalyst performance shortcomings. Side-by-side comparison fosters a more accurate benchmarking of the catalysts, providing reliable data on activity, hydrogen consumption, and the ability to process that feedstock, ultimately leading to improved performance.
- Refiners can make better-informed decisions by comparing multiple catalyst options based on objective performance metrics. A recent example for a diesel hydrotreating (DHT) unit catalyst selection showed that without testing, none of the catalysts proposed by suppliers would meet the target cycle length.
- Selecting the best-performing catalysts leads to improved product yields, lower utility consumption, and the ability to process lower-cost feedstocks, ultimately enhancing refinery profitability. Small changes in naphtha reforming C_5+ yield can significantly impact refinery margins. For example,

a 0.5% shift from C_1-C_4 to C_5+ can result in an annual gain of €800,000. According to Pongboot *et al*, a performance gap between the best catalyst and an average one for a 54,000 bpd hydrocracker could be up to $20 MM/yr.[3]

Multiple catalyst options undergo rigorous testing under conditions similar to those of existing processes, culminating in an economic evaluation to determine the most advantageous catalyst system for the refinery.

Challenges

Despite its many advantages, independent testing is not without challenges. Testing companies may lack comprehensive context regarding certain functionalities or intricate aspects of the evaluated catalysts:

• Industrial vs laboratory-scale fixed-bed reactor: Pilot plant testing aims to reproduce the industrial process in a shorter period of operation. Experimental aspects require consideration to ensure meaningful results and minimum biases between catalyst suppliers.[3,9]

Since most pilot plants are once-through, the only way to simulate a two-stage hydrocracking process is to split the process into two parts:

> **It is important to select testing facilities with qualified testing methods and resulting data quality supported by catalyst experts with actual refinery experience**

❶ First-stage hydrocracking experiment: use fresh feed (Vacuum gasoil [VGO], Heavy coker gasoil [HCGO], deasphalted oil [DAO]) from the refinery with the target first stage per pass conversion.

❷ Second-stage hydrocracking experiment: use recycle feed (unconverted oil [UCO]) from the refinery with the target second stage per pass conversion and recycle feed rate.

Continuous catalytic reforming (CCR) is a moving bed process that is simulated in a fixed-bed pilot plant. In CCR operation, the catalyst is circulated between reaction and regeneration sections with a much slower space velocity compared to reactants. In a fixed-bed pilot plant simulation, there is no catalyst movement.

• Data normalisation is crucial for fair comparisons between catalysts, particularly when variations in product cuts could distort results. By correcting for interferences, such as the presence of inert gases and specific hydrocarbons in the product streams, evaluations can better reflect the true performance of catalysts.

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Common pitfalls

An article by Vilela *et al*[2] highlights several pitfalls in catalyst selection that should be considered in independent testing, including:

• **Overreliance on catalyst vendor proposals**

Issue: Refiners often fully trust the catalyst vendor's proposal, which is based on proprietary kinetic models. These models, while grounded in core principles like Langmuir-Hinshelwood kinetics, vary in assumptions and accuracy.

Impact: Vendors may adjust product yields and properties to make their proposals more attractive, leading to potentially misleading results.

Solution: Refiners should benchmark catalysts in trustworthy independent testing facilities to ensure accurate performance evaluation.

• **Lack of testing**

Issue: Most catalyst selections do not include catalyst testing or a proper selection of catalyst options. Not all catalysts are commonly tested and are often overlooked.

Impact: Minor performance flaws in large processing units can lead to significant financial losses.

Solution: Rigorous testing of all refining catalysts is essential to avoid costly performance issues.

• **False assumptions**

Issue: Refiners may presume that the catalyst vendor with the largest market share provides the best catalyst.

Impact: Market leaders do not always offer the highest performing catalysts. Independent testing has shown that some non-market leaders develop superior catalysts.

Solution: Refiners should evaluate multiple catalyst suppliers through independent testing to identify the best-performing catalysts.

• **Prioritising cost over performance**

Issue: Refiners may choose cheaper catalysts to save costs.

Impact: Selecting subpar catalysts can result in financial losses far exceeding initial cost savings.

Solution: Refiners should focus on catalyst performance rather than price, as the long-term benefits of high-performing catalysts outweigh the cost differences.

Insights

Vilela *et al* highlight several key aspects that further underscore the importance of independent testing:[1]

• Changes in feedstock quality can significantly affect catalyst performance, making pilot plant studies essential to predict these impacts accurately.

• High-throughput testing with the use of the proprietary Flowrence technology allows for the simultaneous testing of up to 16 different catalysts under identical conditions, providing reliable and statistically significant results.[8]

• Independent testing enables refiners to compare multiple catalyst options cost-effectively, ensuring the selection of the most efficient catalyst by delivering accurate performance data to support better long-term planning and operational decisions, ultimately enhancing refinery profitability.

Naphtha reforming catalyst testing

This case study provides a practical example of the benefits of independent catalyst testing in naphtha reforming.[4]

Catalytic reforming is crucial for producing high-octane reformate for gasoline blending and high-value aromatics. It also serves as a primary hydrogen producer for refineries. Small changes in yield can significantly impact refinery margins. For example, a 0.5% shift from C_1-C_4 to C_5+ can result in an annual gain of about €1M.

Test results from the micro-pilot plant were consistent with the commercial steam reforming (SR) reformer data, with a small difference of 0.65 wt% in C_5+ yield and 0.10 wt% in hydrogen production. The high data quality and reproducibility of the pilot plant tests provide refineries with confidence in selecting the best-performing catalysts.

DHT catalyst loading to process more LCO

This case study highlighted the value of independent testing for the optimisation of DHT catalyst loading schemes.[5]

Light cycle oil (LCO) has a lower cetane number and higher aromatics content compared to straight-run middle distillates, making it challenging to process. Processing LCO requires higher hydrogen consumption and more severe hydrotreating conditions to meet ultra-low sulphur diesel (ULSD) specifications.

The previously mentioned high-throughput unit with 16 parallel reactors was used to evaluate different catalyst configurations (CoMo, NiMo, and stacked beds) with varying LCO blending ratios. The testing focused on hydrogen consumption, cycle length, and aromatics content to determine the optimal catalyst loading scheme, with the following results:

- NiMo catalysts showed higher hydrogen consumption due to their superior hydrodenitrogenation (HDN) and hydrodearomatisation (HDA) activities.
- The CoMo/NiMo/CoMo scheme provided a good balance between catalyst activity and hydrogen consumption, achieving ULSD specifications with a relatively low start-of-run (SOR) temperature.
- The optimal catalyst loading scheme ensured compliance with aromatics content and product density limits, enhancing overall diesel quality.

DHT catalyst selection

The DHT case study provides further insights into the importance of independent catalyst testing.[6] DHT is complex due to low net conversion rates, minimal hydrogen consumption differences, and varying product properties. Selecting the best DHT catalyst is a challenging task due to small differences in product yield, hydrogen consumption, and product properties. The level of catalyst activity can only be determined through testing.

The testing programme involves scaling down commercial operations to lab-scale experiments, ensuring accurate representation of reactor conditions. In this effort, the Flowrence system allows for efficient testing of multiple catalyst systems, providing high-quality data for economic evaluation.

The study highlights the importance of selecting the right catalyst configuration (CoMo, NiMo, or stacked beds) to balance hydrogen consumption and maintain product specifications. However, no catalyst option can meet the unit cycle length target.

Key takeaways

Independent testing provides reliable data on catalyst performance, ensuring refiners can make informed decisions based on accurate and unbiased results. As refineries seek to justify their catalyst selection decisions, there is an increasing demand for side-by-side testing and third-party evaluations.

Such independent assessments serve as vital quality control mechanisms, ensuring that refineries select catalysts that align with their operational goals and economic criteria.[7] This trend mitigates the risks associated with supplier changes, new feedstocks, co-processing, and new catalyst developments.

Selecting the optimal catalyst can significantly enhance refinery profitability by improving product yields, reducing utility consumption, and enabling the processing of cheaper feedstocks. High-throughput screening technologies allow for the simultaneous testing of multiple catalysts under identical conditions. This approach accelerates the evaluation process and provides statistically significant results, enabling faster and more reliable catalyst selection.

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