OPTIMAL HYDROPROCESSING REACTOR PERFORMANCE

A review of hydroprocessing reactor internals and recent advancements in the technology that improve the performance of hydroprocessing units.

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Worldwide, demand for high-quality distillates continues to increase, as does the number of markets that require very low sulfur content in the finished product. Hydroprocessing plays a critical role in the production of clean, high-quality fuels and the safe and efficient operation of refineries.

Hydroprocessing technologies have continued to improve, especially over the past five years, incorporating research and development breakthroughs with feedback from operating units and changes in industry standards and equipment design. As a result, significant advancements in energy optimization, product recovery systems and reactor internals design have been made.

While design elements including catalyst and metallurgy can be optimized to improve operations, this article focuses on the importance of reactor internals to achieve processing objectives. Refiners can realize significant performance gains as they work to meet increased market demand for high-quality fuels by upgrading hydroprocessing reactor internals in either newly designed units or in existing reactors that are undergoing revamps or catalyst reloads.

Overview of reactor internals

In the hydroprocessing reactor, the hydrocarbon feed is reacted with hydrogen over a fixed bed of catalyst at an elevated temperature and pressure. For petroleum fractions heavier than naphtha, the mixture of hydrocarbon feed and hydrogen typically consists of two phases: a liquid phase and a vapor phase. In order to use the catalyst efficiently, the liquid and the vapor must be distributed uniformly across the reactor cross-section.

Non-uniform distribution of vapor and liquid results in lower product quality, hot spots in the catalyst bed, increased catalyst deactivation rate and/or a shorter cycle length compared to uniform distribution. The full potential of the catalyst in a reactor can only be attained with properly designed reactor internals. Even the best catalyst will not be used to its full potential with ineffective reactor internals.

The main components of hydroprocessing reactor internals can be seen in Figure 1. Top head internals include an inlet diffuser and top trays to break the momentum of process fluid entering the reactor, and they provide even distribution over the catalyst system.

In order to control the exothermic reactions, a typical hydroprocessing reactor is constructed with multiple catalyst beds with quench zones in between where cold hydro-

gen quench gas is introduced, thermal equilibrium is established and then the vapor and liquid are distributed over the next catalyst bed. At the bottom of the reactor, an outlet collector is installed to avoid the migration of catalyst to downstream equipment.

The vapor/liquid distribution tray is located at the inlet of each catalyst bed and is responsible for the final distribution of the process streams over the catalyst. Each distribution tray consists of many individual distributors or caps.

Earlier generation vapor/liquid distribution trays used bubble caps. Since then, many companies have recognized the importance of internals to hydroprocessing and have developed increasingly sophisticated distributors.

There are several types of distribution trays available in the market today from a variety of suppliers that fit into two main categories: vapor-lift (or bubble cap) and chimney style. The bubble cap tray uses the vapor to lift the liquid over an internal weir in each distributor. The chimney-style distributor relies on the liquid column over some liquid openings to provide the pressure required to pass the liquid through these openings. In fact, previous generations of UOP proprietary internals included both vapor-lift and chimney-style trays.

Reactor internal design challenges

Performance in out-of-level conditions: Under ideal conditions, where distribution trays are perfectly level and the vapor-to-liquid ratio remains constant, most distribution devices will likely provide adequate performance. However, tray level differences almost always exist due to fabrication and installation tolerances, level gradients and waves in the liquid level and normal deflection of the tray in operation.

This could also result from the design of the reactor internals. Moreover, vapor-to-liquid ratios may vary significantly during an operating cycle or shifts in conversion level. This causes an appreciable variation in the liquid level on the tray and pressure at different points above the distribution tray, resulting in uneven distribution across the catalyst bed below.

Operational flexibility: Another common challenge is the rangeability of the internals, or the operating range in which the internals will continue to provide even distribution. Various types of distribution trays will perform satisfactorily at the operating conditions for which they were designed, but they do not provide for much operational flexibility. Refiners operate units for many years without changing their internals and often will increase or decrease feed rates as their needs change over time.

Installation and maintenance time: Time required for installation and maintenance also is a concern. Unit shutdowns cost millions of dollars, so minimizing downtime is critical. The ability to install internals quickly and have easy access for cleaning and maintenance during turnarounds is paramount. If a distributor tray is extremely crowded and difficult to clean or prone to plugging, it can cause significant delays in turnaround time, which results in lost profit.

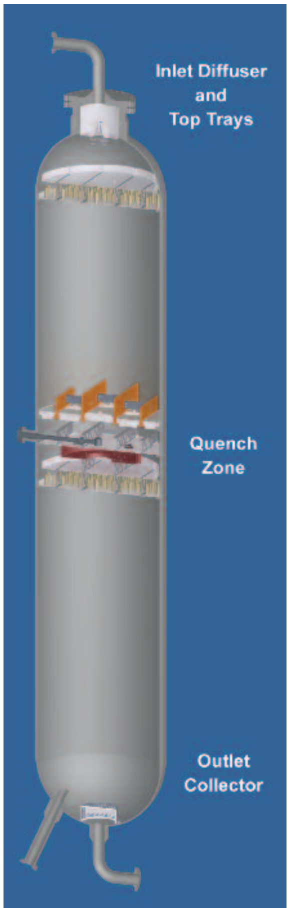


Figure 1 Hydroprocessing reactor internals
Source: UOP

Benefits and drawbacks of current technology

Vapor-lift distributors: For vapor-lift distributors, the change in liquid level on the tray caused by a given change in liquid flow is small; therefore the liquid flow rangeability of the device is large.

The relatively high-vapor flow velocity through the slots tends to keep the slots free of fouling. The drawbacks of

Figure 2 Cold flow test column *Source: UOP*

this style distributor are that liquid maldistribution due to out-of-level situations and pressure differences above the tray are typically high. This is especially true in hydroprocessing reactors with a high vapor load.

In order to combat these maldistribution issues, the total flow areas through the distributors must be maximized and, consequently, the distribution units have to occupy a large fraction of the tray area. This is detrimental to performance as liquid has a hard time flowing from one area of the tray to another, causing liquid level gradients. It also makes the tray crowded and difficult to clean during turnarounds.

Chimney-style distributors: The chimney-style tray offers reasonable liquid distribution in terms of acceptable performance in out-of-level situations and pressure differences, but only through a limited flow range. Unlike the vapor-lift tray, the liquid level varies significantly on chimney trays when the liquid flow to the tray is altered. At high liquid flow, the chimneys will overflow. At low liquid flow, the liquid drops to a level near the lower liquid holes. Both situations result in liquid maldistribution.

A new approach to reactor internals technology

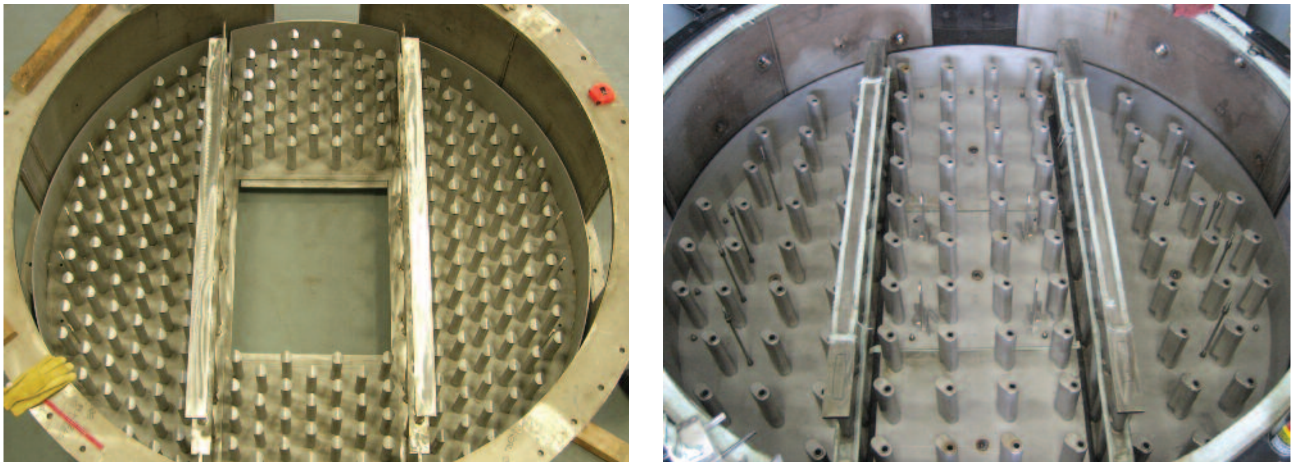
The challenge in developing a new style of distributor is the ability to take mathematical models and computer flow models and actually test them to confirm performance. It can take years before a distributor design will be used in a commercial unit, and it can be risky to make significant changes to the design before confirming how the reactor internals will perform in an operating unit.

Additionally, operating units typically are not designed with the ability to measure the actual distribution at the outlet of a tray. Rather, refiners must rely on temperature spread data to confirm performance, which does not give as much information as needed to accurately evaluate the performance of a new design.

To address this challenge, UOP commissioned a commercial-scale cold flow test column in 2011, which can be seen in Figure 2. The capacity of this column is approximately equivalent to a 40,000-barrel-per-day commercial reactor. This cold flow test column allows visual observation of the different quench zone components in operation and enables measurement of micro and macro distribution and quench zone thermal mixing efficiency.

The column enabled testing and evaluation of different novel distributor ideas, including the UOP "Uniflow" design. The Uniflow distributor is a hybrid of the chimney and vapor-lift cap technologies. Taking the best of both technologies, it is the only hybrid style distributor available today.

In this design, all distributors on the tray pass nearly identical liquid flow rates regardless of tray levelness and pressure differences above the tray. Liquid maldistribution due to tray out-of-level or pressure differences above the distribution tray is very low throughout a very large liquid flow range. The liquid flow rangeability of the hybrid distributor typically allows for operation at 10% to 120% of design (12:1 rangeability), with minimal impact on distribution performance.



Previous Generation | Uniflow-VL tray

Figure 3 Previous generation vs. Uniflow design *Source: UOP*

For comparison, a chimney-style distributor has a maximum range ability of 6:1. The hybrid distributors also achieve uniform local liquid spread from each distributor onto the downstream catalyst bed surface. This wider coverage allows Uniflow distributors to occupy a smaller fraction of the distribution tray total area.

As seen in Figure 3, the Uniflow vapor/liquid tray features a larger open area between distributors than previous generation technology, using about one-third of the number of distributor devices. The distributors also are resistant to fouling because their large flow openings and sufficient spacing between the liquid inlet, and the tray allows for any scale accumulation that may occur.

This new distributor technology helps enable refiners to get more out of their units. Table 1 shows an example of one refiner that was able to increase unit throughput by 15%, while still reducing temperature spreads across the catalyst beds by up to 8 C. Table 2 shows an example of another refiner that significantly reduced temperature spreads at 32% higher feed rate.

Evolutionary improvements

Reactor internals play a critical role in the successful performance of hydroprocessing reactors. The distributor design is the most important and has evolved with particular improvements in the past several years. By combining the benefits of both vapor-lift and chimney-style distributors into a hybrid design, UOP has developed an improved solution that delivers operational and maintenance benefits, supported by large-scale development testing and commercial experience.

Refiners are encouraged to carefully consider the role that hydroprocessing reactor internals play in meeting their processing objectives to make the best selection. ■

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Table 1 Unit Operating with 15% Higher Feed Rate vs. Previous Cycle

HYDROCRACKING BED	RADIAL SPREAD (C) NEW CYCLE	RADIAL SPREAD (C) PREVIOUS CYCLE
Bed 1	Top: 1 Bottom: 3	Top: 1 Bottom: 4
Bed 2	Top: 3 Bottom: 6	Top: 3 Bottom: 10
Bed 3	Top: 4 Bottom: 2	Top: 6 Bottom: 10
Bed 4	Top: 3 Bottom: 7	Top: 4 Bottom: 9

Source: UOP

Table 2 Unit Operating with 32% Higher Feed Rate vs. Previous Cycle

HYDROCRACKING BED	RADIAL SPREAD (F) NEW CYCLE	RADIAL SPREAD (F) PREVIOUS CYCLE
Bed 1	Top: 1 Bottom: 1	Top: 3 Bottom: 18
Bed 2	Top: 4 Bottom: 3	Top: 2 Bottom: 6
Bed 3	Top: 4 Bottom: 2	Top: 5 Bottom: 6
Bed 4	Top: 4 Bottom: 3	Top: 12 Bottom: 36
Bed 5	Top: 4 Bottom: 4	Top: 11 Bottom: 45

Source: UOP