COVER STORY

# NEXT GENERATION FILTRATION

**Tim Michalec, James Esteban, Will Bridges and Tom Ventham, UNICAT Catalyst Technologies, LLC,** explore how innovative next generation technology can help to increase bed cycle time and efficiency, while reducing costs and improving profitability.

Catalyst use in fixed bed reactors pre-dates the refining and petrochemical industries and is considered an essential component over a broad scope of applications. While fixed bed reactors are found in a wide variety of applications, there are many similarities between these operations despite a rich diversity of reactants and products.

Fixed bed reactor systems have two key failure modes which act to reduce the overall activity and life of catalyst bed materials:

- Feed poisons.
- Pressure drop (dP) due to particulate fouling (Figure 1).

Poisons that enter with feed impair the conversion abilities of primary catalysts and therefore impact product quality. Control of poisons, and resistance to impurities, are essential components of fixed bed reactor catalyst system design. Inherently, fixed bed reactors are also exceptional physical filtration devices. Unfortunately, this results in susceptibility to premature shutdown when overall system dP exceeds design parameters due to excessive fouling. Graded bed materials have been used at the inlet of hydroprocessing and hydrocracking reactors for decades to trap foulants and poisons.

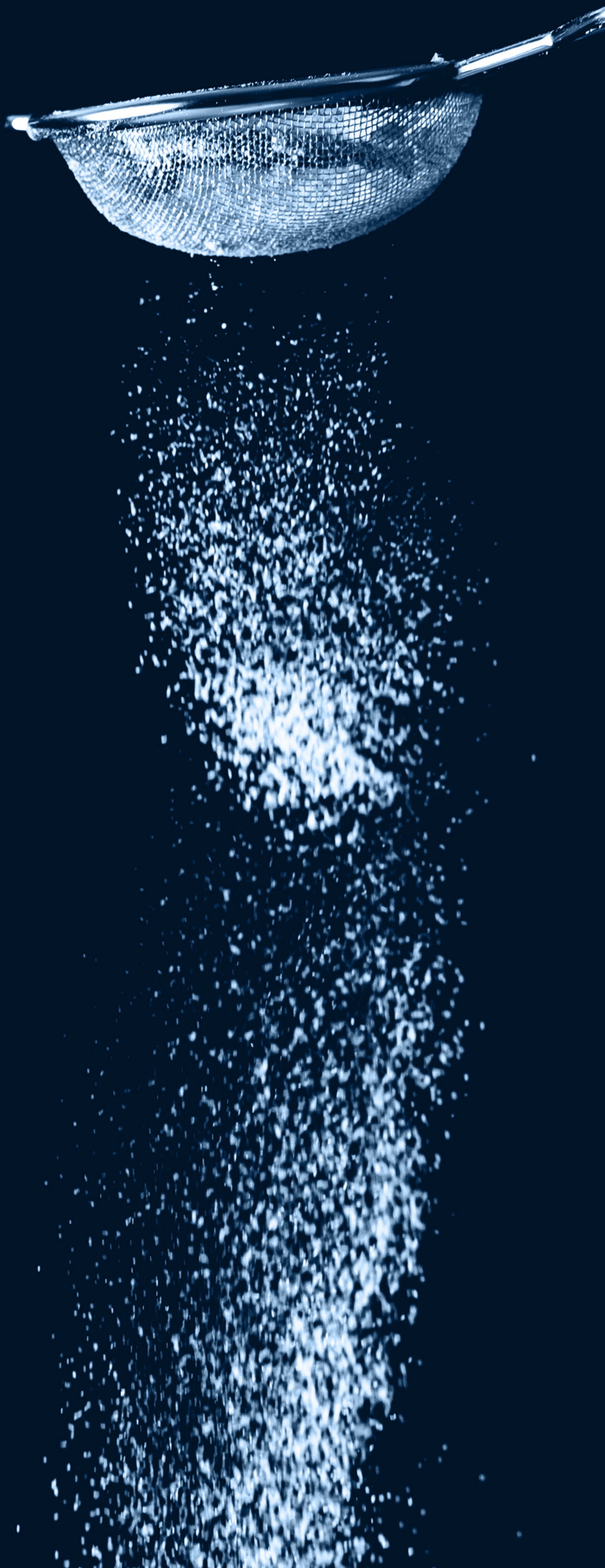
## First generation: deep bed filter using spherical ceramics

Catalyst companies initially developed top bed grading systems targeting foulant filtering with varying degrees of success. Initially a series of smaller spherical supports were used that became known as 'deep bed filtration'. A properly designed deep bed filter, based on particle size and distribution, will remove large proportions of particulate matter, provided it has sufficient depth. The problem is that it requires a significant portion of a catalyst bed to work properly, reducing the amount of active catalyst that can be used. A second problem is that only external void fraction can be used to filter particulates. Thirdly, accumulation of particulates in external void spaces redirects flow to paths of least resistance. Over time, decreased flow accessibility to the catalyst below was due to plugged sections of top bed grading.

## Second generation filter systems: 'wagon wheels' and rings

Replacing inert support balls with 'wagon wheels' and rings improves internal flow channels around plugged external void spaces and improves flow. Filtering remains limited to external void spaces between wagon wheels. Run length is not dramatically improved when using wagon wheels and rings because internal void spaces of the smallest rings remain too large to filter the smallest particulates ('fines'). Fines are trapped at interfaces between the smallest ring layer and main catalyst bed, which is the only external void fraction small enough to capture small particulates.

Accumulation rapidly builds at this interface, void space decreases, dP increases, and end of run (EOR) due to high dP is quickly realised. Since the internal void space of wagon wheels and rings do not effectively filter or collect particulates, grading depths remain large to generate sufficient void space to be effective. Many industrial users must cut feed rate or skim the reactor when encountering high dP limitations. Both options reduce uptime and output, and analysis is required to determine the most cost-effective selection. At times, refiners find that a full discharge and reload with fresh catalyst and grading is more cost effective in comparison to the time and cost of multiple skims.



## Third generation: advanced shapes for effective particulate filtration

Rings and medallions layered above the main bed catalyst was an innovation that produced a small step change in reactor system life cycles. This was further improved with the invention of reticulated ceramics, which enhanced particulate removal and reduced dP build during runs. Finally, a new product entered the market with regular fixed triangular openings that proved additional benefits beyond reticulated ceramics. These advanced filtration system (AFS) disks had higher strength, more disks per $ft^3$, higher particulate pick-up capacity, and an overall deep bed filtration which led to even longer runs with lower dP build.

Adaptation to deep bed filtration systems has been a staple in catalyst system design for over a generation. It is this critical component of reactor system design where UNICAT Catalyst Technologies continues to study, innovate and develop new solutions to advance overall reactor system performance. The company's AFS technology couples next generation computational fluid dynamics (CFD) and process modelling to design products that can maximise performance. By fundamentally restructuring the way that grading material functions in a deep bed filtering process, AFS significantly reduces dP build, which delays onset of EOR dP limits and can increase flow through a vessel without an increase in bed depth.

This paradigm shift is achieved with AFS by facilitating full access to all internal void space for particulate capture (Figure 2). As a result, less grading bed depth is required as internal void space collects particulates, without compromising external void space availability for fluid flow. Lower initial start of run (SOR) dP is also typically observed with AFS due to the higher overall void space.

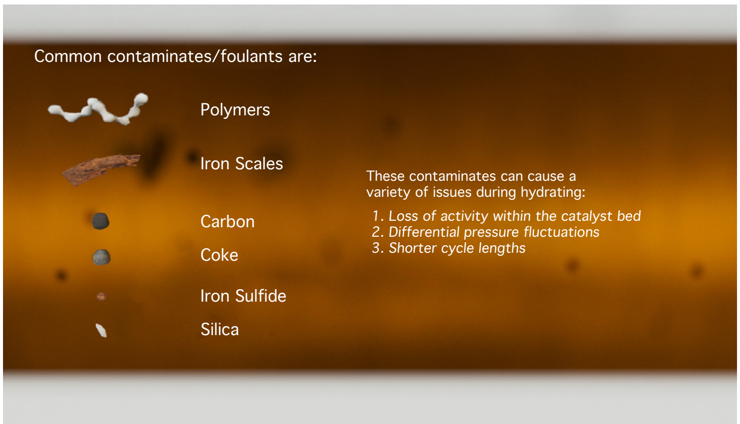



**Figure 1.** Common contaminates/foulants found in feed.

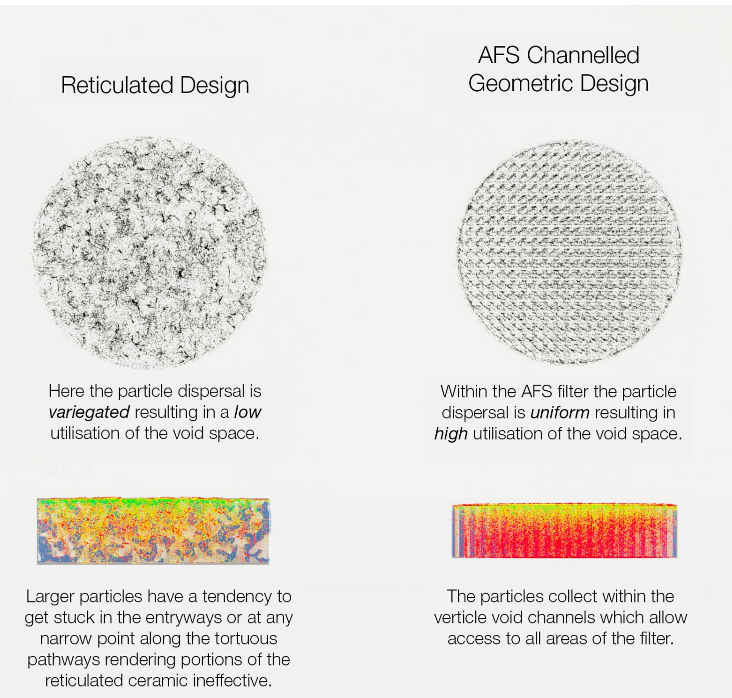



**Figure 2.** Reticulated vs AFS channelled geometric design.

Other improvements that can be observed include uniformity of reactor radial temperature distribution, due to a reduction of dead spots in catalyst layers beneath areas of plugged top grading. The internal void space of AFS is dimensionally controlled using various triangular-shaped mesh grades that are sized for different particulate diameters within an overall range of 10 - 2500+ µm. Required layer depth of different mesh sizes is calculated to optimise removal of the full range of particulates present in the process to maximise time before EOR dP is reached. UNICAT designs AFS loading schemes through careful analysis of particulate size distribution in reactor feed samples, observations from previous cycles (when using AFS or other advanced or basic grading technologies), and engineering experience.

While the functional objectives of AFS have remained much the same, the shape and design has evolved based on CFD modelling of filter capacity and system dP. A primary beenfit of AFS is durability, which is directly related to composition and shape. It is important to refiners that catalyst and grading materials exhibit exceptionally high robustness and crush strength. This is essential to withstand operating conditions and is also vital during transportation and loading activities. Breakage or damage to fresh materials loaded into fixed bed reactors leads to an elevated dP beginning from SOR.

Furthermore, when replacing only a portion of the catalyst load during a skim, it is of paramount importance that no additional small particles are introduced to the existing catalyst bed below. A geometric design and a uniform structure provide AFS with high durability and crush strength. The mesh structure provides exceptionally high useable void space relative to alternative technologies. These dual benefits provide refiners with advantages in both reduced dP for longer days on stream pressure, as well as enhanced protection of main bed catalyst materials.

## Shape and size

Many examples exist in literature which highlight the importance of catalyst shape and size in terms of how these parameters influence activity, especially relating to fluid dynamics, diffusivity, and mass transfer. Therefore, it is equally important that shape and size be considered for graded bed filtration media to provide enhanced fluid dynamics, without disrupting flow distribution. This is to achieve maximum catalyst utilisation, while providing high surface area and void space for particulate accumulation. AFS functions analogously to distillation column structured packing, where reactor feed passes through engineered channels designed to optimise surface contact without excessive resistance to fluid flow.

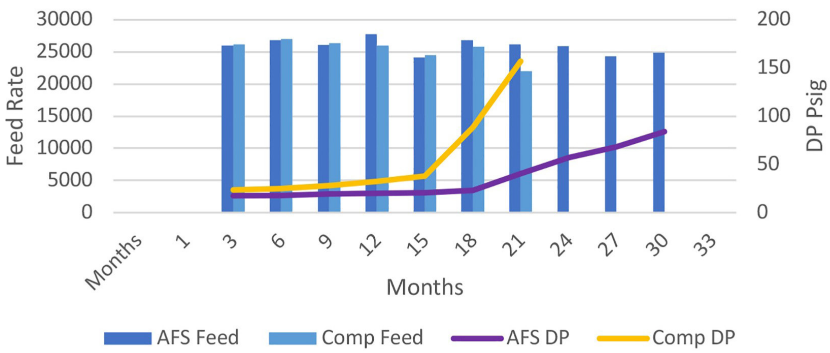



**Figure 3a.** AFS vs competitor grading. Pressure drop and feed rate comparison; with AFS a 150% longer cycle can be realised compared to competitor grading, leading to reduced costs, improved profitability and minimised down time.

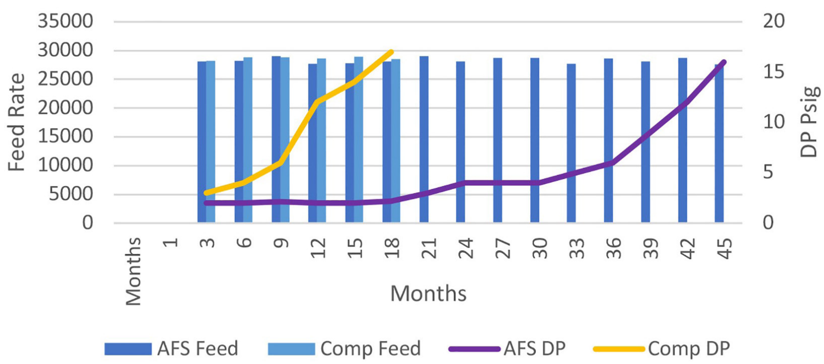



**Figure 3b.** AFS vs competitor traditional reticulated grading.

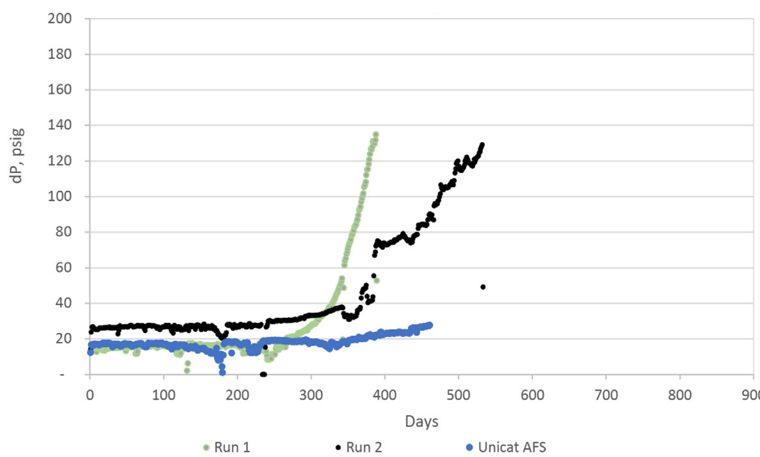



**Figure 4.** Case study: reactor pressure drop with similar feed rates and properties. SOR pressure drop significantly lower compared to the competition, leading to longer cycles and improved profitability.

## Loading

Typically, AFS grading is random packed (sock loaded) to give up to 80% total void fraction. Sock loaded AFS naturally configures in a manner where a significant proportion of the matrix face is exposed to feed flow. In vessels where it is important to load the highest number of pieces possible in order to maximise total contaminant capacity, AFS can be raked during loading in order to load approximately 10% more disks. AFS is also a valuable hold-down material due to its high density (~44+/- 10% lb per cuft). UNICAT has experienced cases replacing lower density grading with AFS to avoid damage previously found in reactors where top bed grading formed into vortex-shapes due to turbidity of feed at the top of the bed, leading to premature dP.

## Active metal promoted options

With catalyst reactors being fixed in size, refiners are looking for ways to utilise every $ft^3$ of space for as much benefit as possible. In addition to the removal of contaminants from feed streams, grades of AFS are available with a variety of enhanced chemical properties, including active versions that provide a staged activity profile as feed is introduced to the reactor bed. This allows many common main catalyst bed poisons to be actively captured on AFS media, in addition to providing mild hydrogenation in hydroprocessing units to protect from deposition of polymeric structures that result from rapid hydrogenation of light hydrocarbon components.

## Future feedstocks

Advancement of co-processing bio-based feedstocks presents new and unforeseen challenges for refiners. The popular solution appears to be to process such feeds in fixed bed reactors, such as hydrotreaters and hydrocrackers. With high costs and short

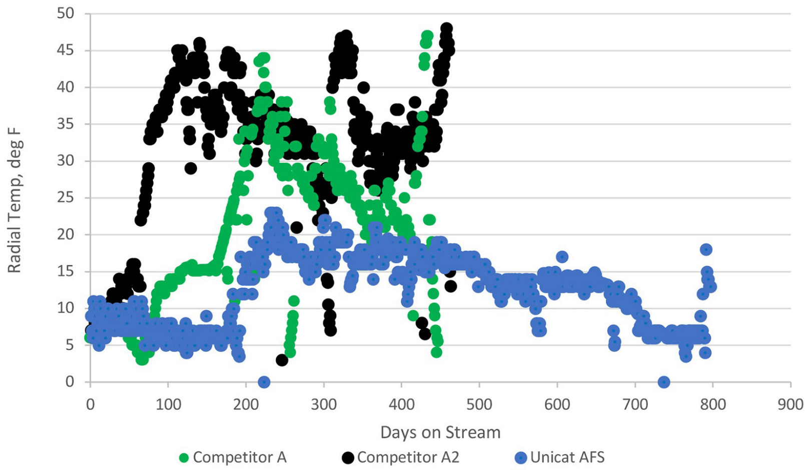



**Figure 5.** Radial temperature profile: AFS vs reticulated grading. Radial temperatures are mitigated with AFS compared to other advanced grading technologies. In this application, AFS also gave significantly longer cycle length at 800 days vs other runs with alternative technology at under 500 days.

lifetimes of advanced catalysts required for such hydroprocessing reactors, maximising the protection of the catalyst bed becomes even more essential. Additionally, the possibility of introducing new contaminants associated with bio-feeds requires careful consideration of the incumbent grading system before commencing such feed processing, such as oxygenates, gums, coke particles from pyrolysis, and other particulate material.

## Conclusion

AFS is an advanced filter technology that can help refiners achieve significantly longer run lengths (Figure 3), lower dP (see Figures 3 and 4), better catalyst conversion retention, improved radial heat profiles (Figure 5), and increased reactor throughputs. This can apply to refiners processing both conventional crude based feeds and bio-based feeds, where challenges may be different, but the solution can be straightforward and cost-effective.

The technology can be applied in any fixed bed reactor or can be provided in flexible, skid-based units to treat flows ahead of a main reactor bed. This second option provides an opportunity to physically separate grading layers from the catalyst bed, allowing greater volumes of catalyst to be loaded to the main reactor, and contaminant management to be conducted more effectively and online, without interruption to the process. While achieving significantly longer run lengths, shorter turnarounds, and less catalyst wastage (i.e., costs), UNICAT supports refiners optimising their reactor loading designs through consecutive cycles to ensure the grading system remains functioning in the best way possible for the operator.